Shared-control framework for smart human-vehicle cooperation in the context of autonomous and assisted driving

Ph.D. candidate

Sebastiano TADDEI

Cycle

XXXVIII

Tutors

Professor Francesco Biral

Professor Gastone Pietro Rosati Papini

1. Description of the research program

During the three years of the PhD, I have the goal of developing a concealed shared-control framework for safer and greener driving. Hereafter the plan for each one of the three years.

First year
During the first year I will focus on the development of robust mechanics-informed neural networks (NNs) to estimate the direct and inverse dynamics of a vehicle. The starting point will be the Virtual Race Driver (VRD), developed by a past PhD student, which aims at achieving minimum lap times on a racing track. The idea is to improve the VRD in each of its parts by using mechanics-informed NNs. At first the goal will be to develop a NN capable of estimating the direct dynamics of a vehicle by taking as input only the pedal and the steering wheel position. With the direct dynamics NN we can develop and train (e.g., using mental simulations) a NN that estimates the vehicle inverse dynamics. These two networks will be implemented in the VRD to control and race a vehicle both in simulation and on the vehicle simulator of the University of Trento (UniTN).

Second year
With the NNs the VRD can handle the human driver inputs but does not predict its intentions nor worries about concealing itself. During the second year I will focus on adapting the improved VRD for the shared-control application. Prediction layers will be added to indulge the human driver intentions, passing this information to the VRD to control the vehicle optimally. Mechanisms to allow the human driver to take control whenever necessary will be implemented and the VRD will be refined to conceal itself as much as possible. The goal is to obtain a version of the VRD ready to be deployed on a real vehicle.

Third year
With the VRD ready for testing, the first half of the third year will focus on deploying and testing the VRD on the automated vehicle-in-the-loop at the Universität der Bundeswehr München. During this period abroad of six months the integration with a Local Dynamic Map (LDM) (i.e., a database that maps the environment of interest) coupled with cooperative perception will also be developed. This combination will allow the VRD to predict the intentions of other entities in the environment and react accordingly. For the remaining half of the year, the VRD will be optimised using the collected data and the acquired experience, completing the main research activity.

Aside from the main research activity, during the PhD I will also focus on three other activities. The first is the development of a neural network framework to design mechanics-informed networks, called Neu4mes, with Professor Rosati Papini. This activity will allow me to dive deep in how neural networks function, and quickly prototype mechanics-informed NNs. The second activity is the supervision of the E-Agle Driverless team, a division of the E-Agle racing team of UniTN. The benefits of this activity are many, such as learning how to manage a team of people and getting hands-on experience with real autonomous racing vehicles. Additionally, I will be able to test the shared-control framework on their racing vehicle, validating the VRD on actual hardware. Lastly, during the first two years I will support some of my teachers in didactic activities relevant to my research activities (e.g., vehicle dynamics, intelligent vehicles).

At the end of each year, I plan to have at least one publication on the developed solutions. During the first year I plan to publish an article on my master thesis on the Special Issue "Emerging Technologies/Products and Advances in Future Transportation Systems" as well as a continuation of the original Virtual Race Driver on Vehicle System Dynamics of Taylor and Francis. During the second and third years I plan to have a paper on the VRD for IROS or ICRA depending on the status of the work close to the deadlines. I will also consider publishing works on Neu4mes depending on the state of the development year by year.

In conclusion, I plan to enrol in courses focused on advanced control techniques, statistical estimation and filtering, modelling and simulation of dynamical systems, and efficient code implementation.

2. Schedule of the research activities

First academic year (planned)

	Description	Period	Activity abroad
Virtual Race Driver	Improve the Virtual Race Driver developed by a past PhD student. The goal is to improve its current capabilities by using mechanics-informed neural networks for the direct and inverse dynamics.	Entire year.	NO
Neu4mes	Develop a functioning prototype of a neural network framework to design mechanics-informed networks.	Entire year.	NO
Supervision of students	Supervise the E-Agle Driverless team. The goal is to have a functioning team and a prototype of the automated driving system for their car.	Entire year.	NO
Integrative teaching activities	Support the teaching of the course "Intelligent vehicles and autonomous driving".	First semester.	NO
	Support the teaching of a relevant course for my research field (e.g., vehicle dynamics, intelligent vehicles).	Second semester.	NO
Preparation of manuscripts for conferences or journals	Publish an article on my master thesis on the Special Issue "Emerging Technologies/Products and Advances in Future Transportation Systems"	October 2023	NO
	Publish the continuation of the original Virtual Race Driver on Vehicle System Dynamics of Taylor and Francis	February-March 2023	NO

Second academic year (planned)

	Description	Period	Activity abroad
Virtual Race Driver	Develop the shared-control framework around the improved Virtual Race Driver.	Entire year.	NO
Neu4mes	Continue the development of the mechanics-informed neural network library.	Entire year.	NO
Supervision of students	Supervise the E-Agle Driverless team. The goal is to have a functioning automated driving system to race their vehicle.	Entire year.	NO
Integrative teaching activities	Support the teaching of a relevant course for my research field (e.g., vehicle dynamics, intelligent vehicles).	First semester.	NO
	Support the teaching of a relevant course for my research field (e.g., vehicle dynamics, intelligent vehicles).	Second semester.	NO
Preparation of manuscripts for conferences or journals	Paper on the Virtual Race Driver for IROS or ICRA	February 2024 or August 2023	NO

	Description	Period	Activity abroad
Virtual Race Driver	Deploy the Virtual Race Driver on the automated-vehicle-in-the-loop at the Universität der Bundeswehr München and combine it with a Local Dynamic Map coupled with Cooperative Perception.	First semester	YES (Universität der Bundeswehr München)
	Refine the developed solution and complete the main research activity (the shared-control framework).	Second semester.	NO
Neu4mes	Continue the development of the mechanics-informed neural network library.	First semester	YES (Universität der Bundeswehr München)
	Continue the development of the mechanics-informed neural network library.	Second semester.	NO
Supervision of students	Supervise the E-Agle Driverless team remotely. The goal is to improve the automated driving system using the lessons learned from the races.	First semester	YES (Universität der Bundeswehr München)
	Supervise the E-Agle Driverless team. The goal is to summarise the developed system as well as to find and train their next supervisor.	Second semester.	NO
Preparation of manuscripts for conferences or journals	Paper on the Virtual Race Driver for IROS or ICRA	TBD	NO

3. Training and research activities plan

First academic year (planned)

	Description	Period	Final Exam	ECTS
A. Ph.D. courses	Linear and nonlinear Kalman filtering: theory and applications	February 2023	No	0.75
	Object oriented modeling and simulation of multi-physics dynamical systems	November 2023	Yes	4
	Neural Networks for Mechanics	TBD	Yes	3
	Fundamentals of statistical estimation theory	TBD	Yes	3
	Model Predictive Control	March-April 2023	No	1 (estimated)
	Numerical optimization. Algorithms and practical implementation	TBD	Yes	5
B. Master's degree courses				
C. Soft skill courses				
D. Participation to seminars	Complex Systems Modeling	TBD		1.5
	Virtual constraints for mechanical systems	June-July 2023		1.5
	Analysis of agent-based opinion formation models	7 November 2022		0.3
E. Participation to international				

	congresses or workshops			
F.	Presentation of research products at international congresses or workshops			
		TOTAL OF ECTS FOR TRAINING ACTIVITIES		20.05
G.	Individual research activity	Virtual Race Driver	Entire year	22.35
		Neu4mes	Entire year	8
H.	Supervision of students	E-Agle Driverless team	Entire year	4
I.	Integrative teaching activities	Support to didactic activities	Entire year	1.6
J.	Preparation of manuscripts for conferences or journals	Publish an article on my master thesis on the Special Issue "Emerging Technologies/Products and Advances in Future Transportation Systems"	October 2023	2
		Publish the continuation of the original Virtual Race Driver on Vehicle System Dynamics of Taylor and Francis	February-March 2023	2
		TOTAL OF ECTS FOR RESEARCH ACTIVITIES		39.95
		TOTAL OF ECTS		**60**

Second academic year (planned)

		Description	Period	Final Exam	ECTS
A.	**Ph.D. courses**	Numerical optimal control: basic theory and applications	TBD	Yes	4
		Scientific computing	TBD	Yes	6
B.	**Master's degree courses**				
C.	**Soft skill courses**				
D.	**Participation to seminars**				
E.	**Participation to international congresses or workshops**	IROS 2024 or ICRA 2024	13-17 October 2024 or 13-18 May 2024		5
F.	**Presentation of research products at international congresses or workshops**	IROS 2024 or ICRA 2024	13-17 October 2024 or 13-18 May 2024		2
		TOTAL OF ECTS FOR TRAINING ACTIVITIES			17
G.	**Individual research activity**	Virtual Race Driver	Entire year		25.4
		Neu4mes	Entire year		8
H.	**Supervision of students**	E-Agle Driverless team	Entire year		4
I.	**Integrative teaching activities**	Support to didactic activities	Entire year		1.6

		Description	Period	Final Exam	ECTS
J.	Preparation of manuscripts for conferences or journals	Paper on the Virtual Race Driver for IROS or ICRA	February 2024 or August 2023		4
		TOTAL OF ECTS FOR RESEARCH ACTIVITIES			43
		TOTAL OF ECTS			**60**

Third academic year (planned)

		Description	Period	Final Exam	ECTS
A.	Ph.D. courses				
B.	Master's degree courses				
C.	Soft skill courses				
D.	Participation to seminars				
E.	Participation to international congresses or workshops	IROS 2025 or ICRA 2025	TBD		5
F.	Presentation of research products at international congresses or workshops	IROS 2025 or ICRA 2025	TBD		2
		TOTAL OF ECTS FOR TRAINING ACTIVITIES			7
G.	Individual research activity	Virtual Race Driver	Entire year		37
		Neu4mes	Entire year		8
H.	Supervision of students	E-Agle Driverless team	Entire year		4
I.	Integrative teaching activities				
J.	Preparation of manuscripts for conferences or journals	Paper on the Virtual Race Driver for IROS or ICRA	TBD		4
		TOTAL OF ECTS FOR RESEARCH ACTIVITIES			53
		TOTAL OF ECTS			**60**

4. List of the publications written by the candidate in the triennium

Sebastiano Taddei

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Professor Francesco Biral

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Professor Gastone Pietro Rosati Papini

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