Gulliver: A Test-bed for Developing, Demonstrating and Prototyping Vehicular Systems *

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Ultimately, vehicular systems are expected to gear vehicles with autopilot capabilities, improve safety, reduce energy consumption, lessen CO_2 emission and simplify the control of traffic congestion. This dramatic change will be the result of advances in driver assistant mechanisms for navigating, congestion control, steering, speed controlling, lane changing, avoiding obstacles to name a few. Moreover, other technologies, such as driverless cars and vehicle platoons, might also appear on the road; giving way to future vehicle systems that will be controlled by different types of drivers, i.e., driverless, mechanism assisted drivers and nonassisted ones. We propose to study vehicular systems of low cost miniature vehicles that use wireless communication on a large scale open source test-bed. The test-bed may be geared with onboard sensors, such as cameras, laser, radar, speed sensors, etc. Our approach provides a simpler yet detailed investigation of vehicular systems that will be affordable by a wider range of developers than available today.

Vehicular system designers often use simulation tools to prove new concepts. Simulation tools allow extensive testing of software components, say, by using fault injection methods. Simulators can also deal with complex mathematical modeling of physical objects (e.g., vehicles) and their controlling computer systems (see Figure 1). The computational complexity of detailed simulations of future vehicular systems limits the scale of testing and often does not allow extensive system testing for a large number of vehicles. Additional limitations include the absence of humans in the loop or the assumption that computer programs can always predict driver reactions.

Due to these limitations, the first demonstrations of new vehicular systems are centered around proving grounds and testing tracks. These facilities are not affordably accessible to a wide range of universities, public research and engineering institutes. By reducing the demonstration costs, we could allow a greater engineering force to participate in the efforts for greener transportation systems with near zero fatalities.

Gulliver as a toolkit Recent advances in the field of mobile robots allow the ad hoc deployment of a fleet of miniature vehicle that are controlled remotely by human drivers or computer programs. These affordable miniature vehicles can greatly simplify the development of the cyber-physical layer of new vehicular systems (see Figure 1). Namely, a prototype experimenter can test the vehicle system that is installed on the miniature vehicle platform. These tests can include onboard fault injection. Moreover, the experiment execution can be logged and later replayed and visualized in the simulator.

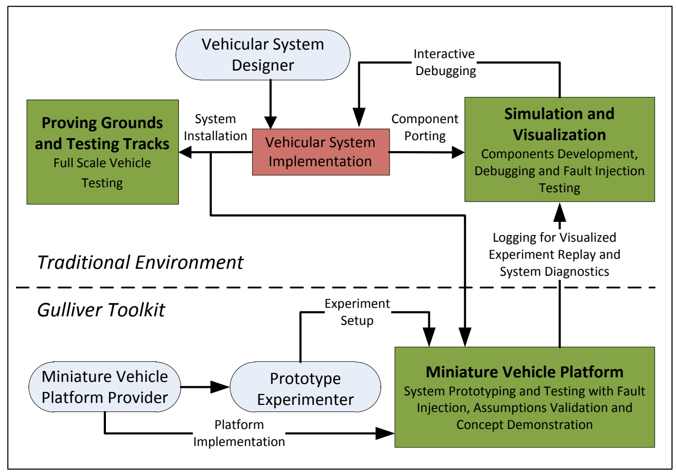

Fig. 1. Traditional development environment and the Gulliver toolkit are depicted above, and respectively, below the dashed line. The traditional development environment allows the vehicular system designer to simulate and visualize components of the vehicular system before installing it and testing it in proving grounds and testing tracks. The Gulliver toolkit allows the prototype experimenter to use the test-bed for setting up an experiment in which the vehicular system is tested over a miniature vehicle platform. The experiment is logged for later execution visualization by the simulator.

In order to bring the prototyping of cyber-physical layer into the practical realm, one can take a range of approaches for emulating and substituting relevant system elements. For example, the human driver can be included in the loop of the miniature vehicle control via an onboard or remote computation, hand-held wireless devices, or driver simulation cockpits with multi-angle video streaming in addition to what looks like, sounds like and feels like emulation of the vehicles and their environment.

We propose a design for miniature vehicle platform, named

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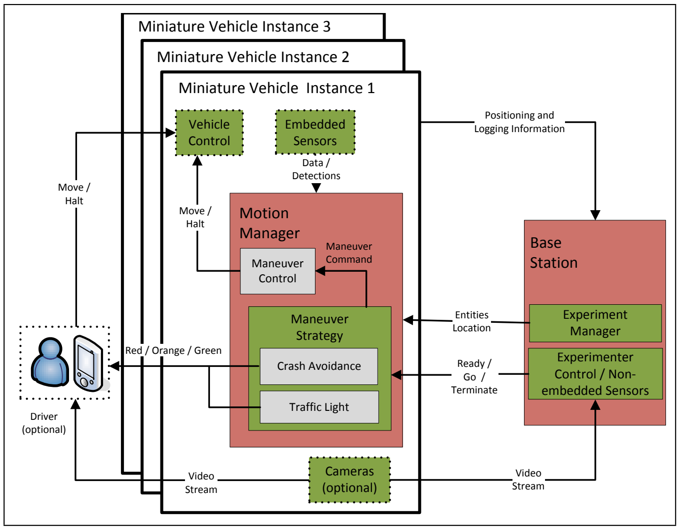

Fig. 2. Component diagram of the Miniature Vehicle Platform. Note that the components that are surrounded by dashed lines are not simulated.

Gulliver, that has the ability to prototype cyber-physical technologies for vehicular systems. We assume that problems related to the interaction among vehicles on the road can be solved before the prototyping phase. Thus, we can follow the approach in which miniature vehicles can represent full-scale vehicles in the test-bed. It is up to the prototype experimenter to decide which relevant parts of the embedded system should be included onboard of the vehicle.

Our approach enables the vehicular systems designer to focus on the cyber-physical aspects of the problem and the validation of the system-related and driver-related assumptions. Thus, the Gulliver test-bed is a multifaceted toolkit for testing, prototyping and demonstrating new vehicular systems. The test-bed feedback capabilities and human interaction units are imperative debugging tools for vehicular system developers.

Design Outline The test-bed includes two subsystems: a Simulator and a Miniature Vehicle Platform (see Figure 1). We first describe the two subsystems before looking into the Motion Manager component.

Simulator The Simulator subsystem allows the vehicular system designer to develop and test new components referred as the Base Station, and the Miniature Vehicle. The simulator's components are depicted in Figure 2 (in solid lines).

The Base Station includes the Experimenter Control that can send to the Motion Manager the key platform command, Ready, Go and Terminate, for initializing, starting, and respectively, terminating the experiments. It also includes the Experiment Manager, which sends to the Motion Manager all the information that is required for moving the miniature vehicles in the platform according to the experiment plan. Moreover, it monitors and controls the experiment by periodically receiving the vehicle's positioning information.

The Miniature Vehicle controls the vehicle motion after receiving data from the onboard sensors and commands from the Base Station. The Motion Manager is the unit that controls the vehicle by issuing the commands Move and Halt. These two commands are generated by the Maneuver Control and allow each vehicle to take a sequence of maneuvers from source to destination along the traveling route.

Miniature Vehicle Platform This subsystem allows prototype demonstration and testing of vehicular systems. During such experiments, the system logs its states for later diagnostics and playback in the simulator (see Figure 1). The logging information can be either stored by the vehicle processing units or transmitted on the fly. Future extensions of our design can also consider onboard fault injections.

In addition, one can validate the designer assumptions regarding the behavior of the human driver. Our implementation considers hand-held wireless devices (see Figure 2). Future extensions can use driver cockpits with multi-angle video streaming in addition to what looks like, sounds like and feels like emulation of the vehicles and their environment.

Motion Manager This key component is mounted on the miniature vehicle and is in charge of receiving sensory information, which includes the vehicle location, and deciding which maneuver the vehicle should take. The maneuvers are controlled by the Maneuver Control. It is up to the Maneuver Strategy to decide on which command each miniature vehicle should take. The Maneuver Strategy must make sure that the miniature vehicles do not crash when traveling to their destinations. In order to do that, we use two mechanisms for crash avoidance and traffic light signaling.

Conclusions Gulliver presents a multifaceted toolkit for testing vehicular systems in a practical realm. It lies between computer simulation and full-scale vehicle models, and as such, it simplifies and reduces the costs of vehicular system prototyping and development. Gulliver's greatest strength lies in its ability to prototype cyber-physical technologies for vehicular systems. By that, it allows the system designer to focus on cyber-physical aspects of algorithmic problems in vehicular systems and their networks. In addition to presenting Gulliver as a concept, we outline the design of its key components and their functionalities, see [1] for details.

Further, vehicular systems will enable vehicular interaction, promote cooperation and will be the first cyber-physical systems to reach the scale of millions of units. Currently, no safety-critical system comes close to this scale. Gulliver design is the first to facilitate the detailed investigation of the vehicle interaction and emerging patterns among hundreds and even thousands of units of a cyber-physical system. These investigations are imperative for the design and development of advanced driver assistance mechanisms, such as virtual traffic lights, vehicle platooning, coordinated contention controls, and coordinated lane changes, to name a few.

References

[1] M. Pahlavan, M. Papatriantafilou, and E. M. Schiller. Gulliver: A testbed for developing, demonstrating and prototyping vehicular systems. TR 2011:14, ISSN 1652-926X, CSE, Chalmers Univ. of Tech., 2011.