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Future Semiconductor Architecture for Safe, Secure, Sustainable and Energy Efficient Electric Micro Mobility

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Abstract

The study presented here systematically assesses future requirements of the electronic architecture of vehicles for electric micro mobility starting with the state of the art in 2020. Based on upcoming general improvements, e.g. for the long-term reliability, and specific functions, like e.g. driver assistance systems for improved safety, a future-proof electronic architecture is presented. Prototypical implementations for two use-cases have been developed and first results are included. Ultra-wide-band (UWB) based localization specifically offers advantages in areas with insufficient access to the sky, which is required for position measurement based on global navigation satellite systems (GNSS). Based on vehicle-to-vehicle (V2V) communication and a time-of-flight (TOF) camera, automated platooning has been implemented and tested for e-scooters. The results of this study show the potential of future electronic architectures for vehicles for electric micro mobility in the context of safety, security, sustainability and energy efficiency.

Keywords: Micro Mobility, E-scooter, Safety, Security, Energy Efficiency, Sustainability, Semiconductors, Electric Architecture, Driver Assistance

Introduction

With the introduction of shared electric scooters in Germany in 2019, the number of electric micro vehicles has been increasing significantly. Within a timeframe of just three months, almost 30,000 shared electric scooters were installed in the country. With more than 7000 shared e-scooters, the City of Hamburg ranked third place in Europe behind Berlin and Stockholm in 2019. Typically, an e-scooter in Hamburg is used for 3.77 moves per day. [1] For short distances of a few kilometres and in sufficiently good weather, an e-scooter is an attractive personal transportation option, since it is quick, efficient and easy to use. Thus, e-scooters are expected to stay as a personal transportation option in cities like Hamburg. However, with their success, the number of accidents of electric micro-vehicles with motorized traffic on one hand and with bicycles and pedestrians on the other also increased. Thus, for the further development of electric micro mobility, protection of all involved parties is gaining relevance. Furthermore, the steep ramp-up and high-cost pressure lead to electronics architectures of existing vehicles, that focussed on immediate availability at lowest development and manufacturing effort without considering upcoming requirements and taking the chance to find an optimized architecture, smartly integrating required functions and components. Existing electronic systems in e-scooters lack long-term reliability, which is a key-factor to make them sustainable and environmentally friendly not just in operation, but along the full life-cycle. In this study, requirements, functions and components of a future e-scooter are systematically analysed and developed. Results are generically valid for all types of vehicles for urban micro mobility. Examples are presented, which were prototypically implemented and tested. A universal electronic architecture for future electric micro mobility is derived, which will allow implementation and overcome existing deficiencies.

Figure 1: Real life "storage" of e-scooters in Stockholm [2]

General Requirements

When assessing the electrical design of current 1st-generation, rental e-scooters, strong questions on the long-term reliability arise. In many cases, they were not built for rental use. Due to the focus on visible components, a steep ramp-up and strong cost pressure, products were built based on existing circuitry mostly taken from other low-cost applications. E-scooters are objects of regular vandalism (see fig. 1) and misuse, e.g. by boarding with several people simultaneously. Thus, a design for a longer lifespan seemed to be unnecessary. The overall lifetime of these 1st-generation e-scooters in field is estimated to be in the range of two years [2]. However, since safety and sustainability are key for a broader acceptance and sustainable business model for the future, the design of next-generation e-scooters is expected to change. As a reference, table 1 summarizes general requirements for current designs to those typical in the automotive industry. While the overall lifetime of an e-scooter is just two years, the actual on-time per day is similar to a passenger vehicle. It is expected that besides new functions, long-term reliability will be a key goal for the next-generation e-scooters.

Table 1: Comparison of general requirements between automotive and e-scooters

Requirement	Automotive 2020	E-scooter 2020
Total lifetime	10 years (15 years)	2 years
Operating lifetime	3500 h (5000 h)	730h (2 years, 1h /day)
Failure rate (ppm over lifetime)	<1	Not communicated

User- and Operator-Functions

As of 2020 the electronic design of a typical scooter includes the following user and operator functionalities:

1. User: Drive
2. User: Lights: Front, Rear (, Break, Indicator)
3. User: Interface to the mobile phone
4. Operator: Localize (base functionality)
5. Operator: Communicate position and status (GSM, LTE)
6. Operator: Charge User (€)
7. Operator: Charge Battery (kWh)

The following functions are considered potentially relevant for a future e-scooter:

8. User: Driver protection, e.g. position-based speed control, emergency braking, protection of vulnerable road users (VRUs), collision warning
9. User: Predictive speed advisory
10. User: Automated platooning
11. User: Advanced navigation, optimized routing (safety, speed, comfort)
12. Operator: Improved localization (precision, coverage)
13. Operator: Vandalism detection and protection
14. Operator: Misuse detection, e.g. maximum weight exceeded
15. Operator: Anti-Theft- and Hacking-Protection
16. Operator: Condition monitoring, advanced diagnostics (e.g. wearing parts, malfunction, battery)

In the next section these functions are mapped to hardware modules, which would allow a consistent and cost-efficient implementation within vehicles for electric micro mobility.

Concept for a unified future-proof HW-architecture for e-scooters

Table 2 shows an overview of the user- and operator-functions mapped to hardware modules, which are either required for implementation or would at least optionally improve a certain function. Lines 1 to 7 contain modules required for implementation of existing 1st-generation functions, while lines 8-16 indicate either required or optional hardware modules for new functionalities. Obviously, the number of modules is expected to increase significantly for the next generation e-scooters. Beyond hardware modules existing (, which will have to be updated and improved), “V2X communication”, “inertial sensors”, “UWB positioning” and the integration of surround sensing by “time of flight (TOF)” or “stereo cameras” will have to be developed and integrated.

Table 2: Mapping of functions to relevant hardware modules (grey: new modules required)

Hardware Modules / Function Number	Central Control Unit	Secure Element	Bluetooth Communication	Cellular Communication	V2X Communication	NFC	GNSS Positioning	Inertial Sensors	UWB positioning	TOF/Stereo Cameras	HMI	Lights Control	Motor Control & E-Motor	Electric Brake	Battery Management & Battery
1	✓												✓	✓	✓
2	✓										✓	✓			✓
3	✓	✓	✓	✓		✓					✓				✓
4	✓						✓								✓
5	✓	✓		✓											✓
6	✓	✓	✓	✓		✓									✓
7	✓														✓
8	✓		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓
9	✓		✓	✓	✓		✓	✓	✓	✓	✓				✓
10	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓		✓	✓	✓
11	✓			✓				✓							✓
12	✓	✓	✓	✓	✓		✓	✓	✓		✓				✓
13	✓			✓			✓	✓	✓	✓					✓
14	✓		✓	✓			✓	✓	✓	✓			✓	✓	✓
15	✓	✓	✓	✓	✓		✓	✓	✓	✓			✓	✓	✓
16	✓			✓	✓		✓	✓	✓				✓	✓	✓

V2x-communication

V2X technology enables direct low latency communication between different road users or between a road user and the infrastructure. It is based on the 802.11 standard for communication in wireless networks, which is also referred to as "Wireless Local Area Network" (WLAN). Frequency bands at 2.4 GHz and 5 GHz are used for communication in stationary applications. In highly dynamic environments, however, such as in the transport infrastructure, the IEEE 802.11p is used [4]. It was specially developed and optimized for vehicle-to-vehicle communication in order to increase traffic safety, meeting special requirements, such as low latency and high reliability. In contrast to stationary applications, a frequency band between 5.850 and 5.925 GHz is used with a data rate of up to 27 Mbps. A special feature of 802.11p is the “ad-hoc communication”, in which the communication partners communicate directly with each other. To ensure that the messages and data packets sent are not manipulated, various security mechanisms are provided for the communication. On one hand, a public key infrastructure (PKI) is used to provide V2X hardware with valid certificates, and on the other hand, digital signatures are used within the messages to ensure data integrity. In addition, security profiles are used to ensure that only authorized V2X units can send the messages permitted for them. The vehicles and infrastructure setup on the test track for automated and connected driving (TAVF, [5]) have been equipped with road-side- (RSUs) and on-board-units (OBUs) based on the 802.11p standard including a private-public-key infrastructure.

Inertial sensors

As of 2020 every smartphone is equipped with an inertial-measurement-unit (IMU), typically containing 3-axis sensors for acceleration, yaw rate and the magnetic field, integrated as a silicon-based microelectromechanical system (MEMS). Besides this very high-volume market, MEMS-based sensors have been integrated in many automotive systems [6] and are in use in high-end measurement applications [7]. Advantages are the very high level of integration and small size, their robustness and low-cost. The defined and standardized integration into shared electric scooters will allow functions like advanced navigation (e.g. bad track detection and avoidance), improved localization (e.g. by dead reckoning), the detection of vandalism and many more.

UWB localization

Ultra-Wide-Band (UWB) localization as a method for relative position measurements has been developed in recent years with a focus on mobile applications like indoor navigation or hands-free access. UWB works with short pulses that cause a wide spectrum in frequency, so that the time of flight (TOF) of a transmitted signal can be determined very precisely. Thus, distance measurements based on the time of flight with the speed of electromagnetic waves can be performed. Accuracies down to 10 cm are possible with localization and ranging through UWB [9]. Using the angle of arrival (AOA) of a signal combined with the measured distance the position of an object can be tracked [10]. Besides the high precision, the use of a wide frequency spectrum reduces noise when measuring distances in an area where frequencies of 2,4 GHz (e.g. Bluetooth, WLAN) or 5 GHz (e.g. WLAN) are commonly applied for wireless communication.

Environmental sensing with TOF- or stereo-cameras

The availability of low-cost high-quality cameras in combination with a boost in embedded computing power made available in current smartphones, opens up the opportunity of integration into micro vehicles for functionalities that require environmental sensing. The advantages of using TOF-cameras or stereo-cameras instead of just one normal camera is that the picture also contains information of the distance to the objects measured. Stereo cameras are working comparable to the human eyes by using the combination of two images which are made at slightly different positions and thus make it possible to calculate the distance to detected objects. A TOF-camera, in contrast, emits light pulses itself and by measuring the time of arrival of the reflected light, the distance to every pixel in the image is calculated. By changing the duration of the light pulse, the maximum accessible distance can be adjusted. A big advantage of TOF-systems is, that the distance to objects is directly calculated for each pixel, which reduces required hardware resources and power. With the system used [11], a framerate of up to 60 fps is possible and parameters can be changed "on the fly" depending on the active use case which makes it highly attractive for using it in platooning in micro mobility.

Prototypical implementations

To further analyse and demonstrate the potential of new functions in electric micro vehicles, two use cases have been implemented and tested.

Improved localization by UWB integration

An electric bike/Pedelec has been equipped with an UWB-based positioning system. A model traffic-light was used as the reference station for relative position measurement. Figure 2 shows an overview of the system setup. A test environment was set up at NXP, Hamburg and tests were performed to compare GNSS- and UWB-based position measurement (Figure 3). Since the test area was surrounded by high buildings, satellite-based navigation is expected to show poor performance.

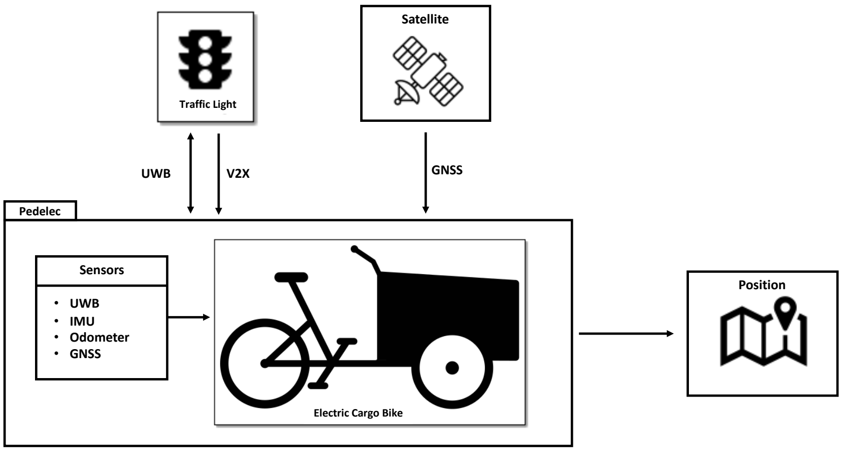

Figure 2: System setup for UWB-based positioning

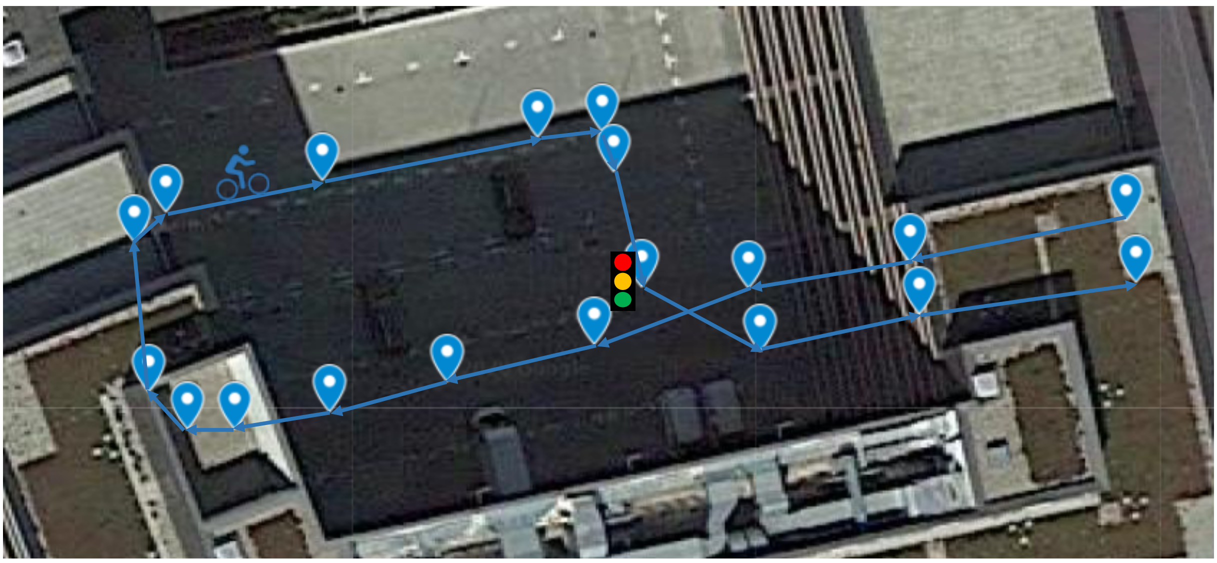

Figure 3: Test measurement performed at NXP Hamburg

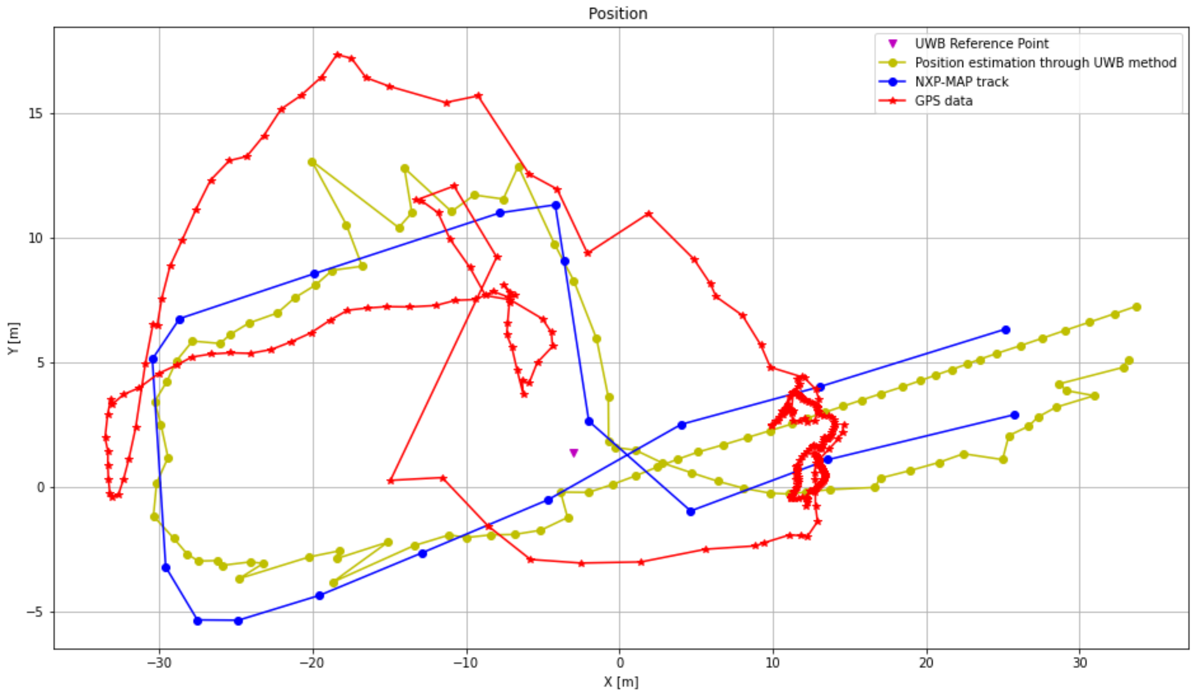

Figure 4: Test results of UWB-based position measurement (blue: real track, red: GNSS, orange: UWB)

As expected, the GNSS-based position measurement deviated significantly from the driving track. The maximum error is estimated to be about 10 m. UWB-based measurement show a significantly smaller error with approximately 5 m distance between the real location and the result of the position measurement. Thus, UWB is expected to significantly reduce the error in positioning specifically in situations with limited access to the sky, which limits GNSS accuracy.

Platooning for e-scooters based on TOF-sensing and IEEE 802.11p communication

Figure 5 shows the system setup for the second use case analyzed in this study. The goal of the development is the implementation of (partially) automated platooning for electric scooters by implementing an adaptive cruise control (ACC), based on object detection and a distance measurement to the next scooter and by implementing an automated exchange of information based on IEEE 802.11p and an extended cooperative awareness (CAM+) message between the involved scooters, the infrastructure and other participants. The result of a first test is shown in Figure 6, which shows the result of the TOF-camera with the scooter and driver at about 3 m in front of the camera.

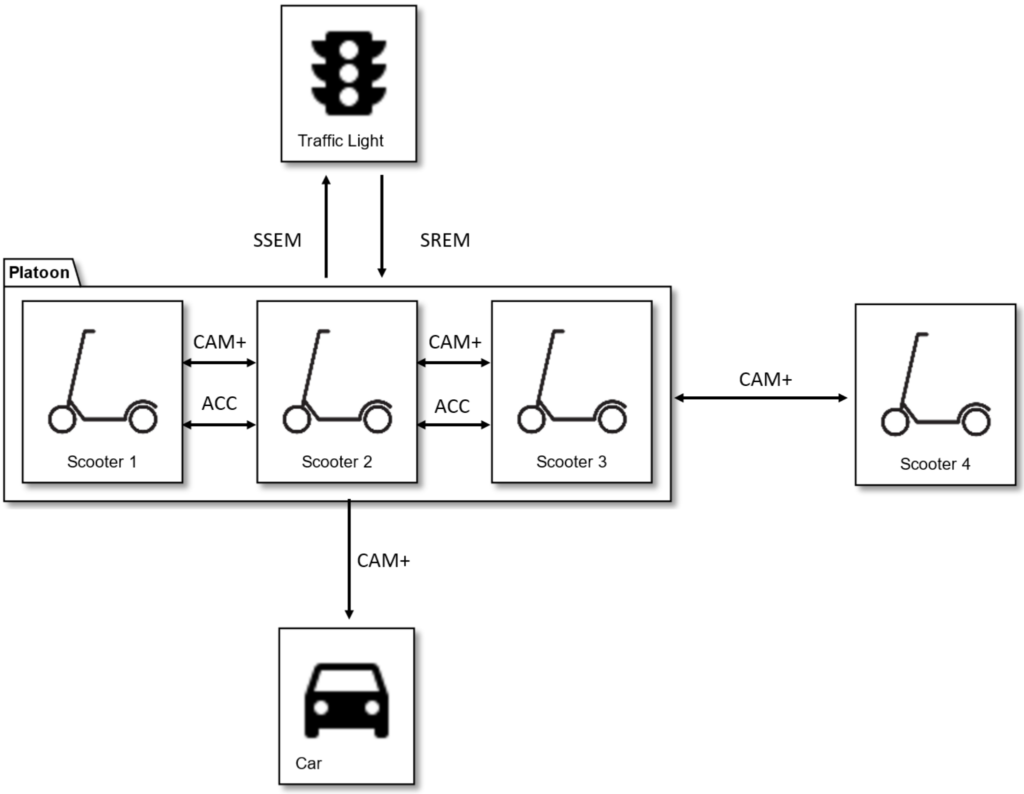

Figure 5: System setup "Platooning"

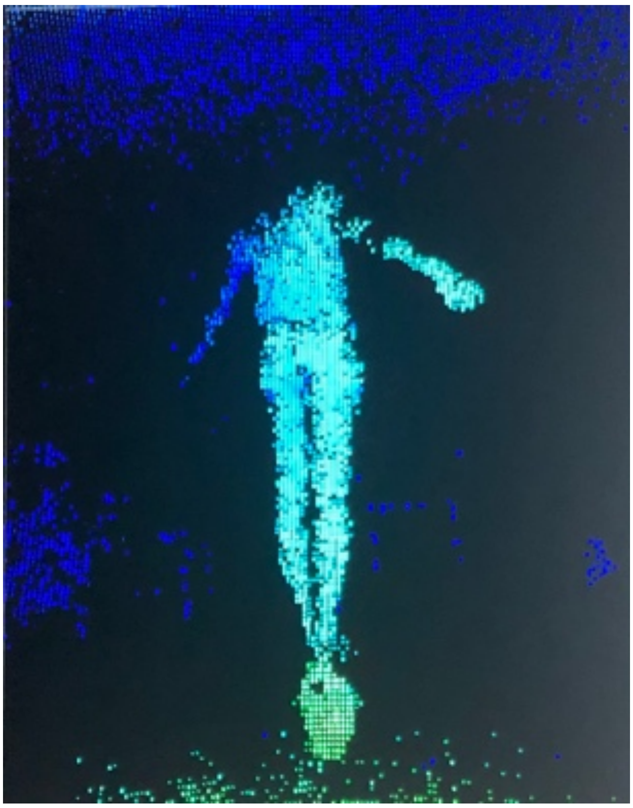

Figure 6: Picture of TOF-camera of a platooning e-scooter at a distance of about 3 m

Conclusion & Outlook

This paper summarizes upcoming requirements and functionalities for next generation shared electric micro vehicles for urban traffic. An electronic architecture is systematically derived based on the current state of the art, general requirements and specific functions. Two prototypical implementations for new functions are presented: UWB-based position measurements in combination with the existing GNSS-based localization could significantly improve the overall coverage in dense urban areas. IEEE 802.11p communication in combination with a TOF-camera-based distance measurement would allow the implementation of automated and safe platooning for e-scooters. As a summary, Figure 7 shows a block diagram of an electronic architecture, that would allow the implementation of functions and fulfillment of upcoming requirements. An electric micro vehicle based on this architecture would improve the current state in all aspects, e.g. safety, security, reliability, sustainability and many more.

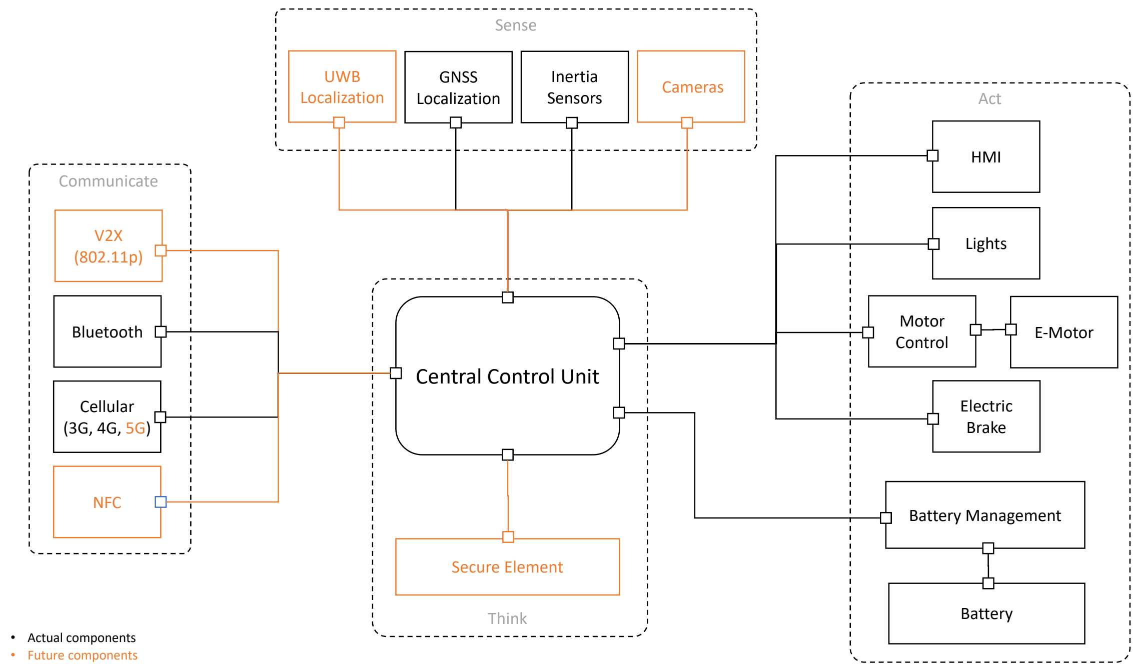

Figure 7: Block diagram for the electronic architecture of a future shared, electric micro vehicle

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