EVS30 Symposium
Stuttgart, Germany, October 9 - 11, 2017

The Development of the Green Safe Smart Light Vehicle Running Chassis for the Urban Multi-purpose Mobility

P.H. Shu[1], Y.T. Lin[2], W.T. Huang[3], J.W. Yang[2], Dr. J.F. Jiang[2], S.Y. Lee[2], N.C.Shiue[2], P.H.Hsieh[2], C.M.Chang[2]

[1] *National Taipei University of Technology, 1, Sec. 3, Zhongxiao E. Rd., Taipei 10608 Taiwan, jphshu@yahoo.com*

[2] *Metal Industries Research &Development Centre, 1001, Kaonan Highway, Kaohsiung, Taiwan, ek.lin@mail.mirdc.org.tw, monicayang@mail.mirdc.org.tw, jfiang@mail.mirdc.org.tw, sylee@mail.mirdc.org.tw, nc_shiue@mail.mirdc.org.tw, evan@mail.mirdc.org.tw, c-ming@mail.mirdc.org.tw*

[3] *Industrial Technology Research Institute, 195, Sec. 4, Chung Hsing Rd., Chutung, Hsinchu, Taiwan, elsie.h@itri.org.tw*

Summary

This paper aims to share the research findings on how to utilize a green safe smart light vehicle(GSSLV) chassis to support urban mobility. A pure electric light vehicle running chassis with 1.8m wheel base in length and 600kg in weight is designed in order to reduce the weight, increase the energy efficiency, and enhance the flexibility of the ICT smart features adaptation. The plug and play of the ICT devices with tailored made scenario maximize the efficiency of the designed chassis as implemented as the car sharing fleet, logistic delivery fleet, personal urban last-mile mobility, or autonomous city surveillance multi-purpose vehicles.

Keywords: Smart Green Light vehicle, electric light vehicle running chassis, urban multi-purpose mobility

1. Introduction

Shared mobility has become the most popular way of urban transportation and will play an important role in reducing carbon emission, saving energy, freeing right of ways, and improving walkability. Driven by shared mobility, connectivity services, and feature upgrades, new business models could expand automotive revenue pools by ~30 percent, adding up to ~USD 1.5 trillion[1]. Three core regions – China, Europe, and the United States – the shared-mobility market was nearly $54 billion in 2016, and it should continue to experience impressive annual growth rates in the future[2]. In spite of the trend of shared-mobility may decrease the car sale, it is not all bad for automakers, suppliers, and the related players to position themselves into the niche market in the near future, such as smart light green vehicle.

[1] 《Automotive Revolution – Perspective towards 2030: How the Convergence of Disruptive Technology-Driven Trends Could Transform the Auto Industry》, Advanced Industries, McKinsey & Company, January 2017.

[2] Anne Grosse-Ophoff, Saskia Hausler, Kersten Heineke, and Timo Möller, "How Shared Mobility Will Change the Automotive Industry", April 2017, available from http://www.mckinsey.com/industries/automotive-and-assembly/our-insights/how-shared-mobility-will-change-the-automotive-industry

The high number of vehicles in urban areas, particularly cities with populations of over 1 million, can lead to issues such as air and noise pollution as well as traffic congestion. Requirements for lowering carbon emissions and Corporate Average Fuel Economy (CAFE) have been implemented across the world and CO2 emissions are expected to be lowered to below 95g/km by 2020. To accomplish this goal, automobile manufacturers must begin developing and selling full electric vehicles or vehicles with clean energy or hybrid power systems, or they will fail in the endeavor. The micro EV is one of the solutions. The development of autonomous vehicles and smart applications has accelerated in recent years. Although the technologies are mostly applied to high-end cars, minibuses or larger vehicles, development in the industry will popularize related key components by lowering prices to levels more acceptable by the market. The usage of the Smart Green Light Vehicle, the issues to be resolved, as well as the adoption of innovative technologies may differ from the existing situation.

Therefore, the requirements for the usage of the Green Safe Smart Light Vehicle in urban areas currently and in the future will inspire applications of innovative technologies. The innovative technologies include the research and analyses of urban transportation issues and their causes, description of usage, market requirements, preferences and restrictions, and incorporate innovations such as Information and Communications Technology (ICT) and Internet of Vehicles (IoV) to predict the status after improvement in order to increase the efficiency, safety, and intelligence in urban transportation. They may also provide more diversified services and big data applications to correctly position the Smart Green Light Vehicle product (specifications, functions, price, target users etc.) and satisfy current demands or create future demands.

Metal Industry Research Development Center (MIRDC) has contributed to the design of chassis for multi-purpose smart light green vehicles in order to keep up with the updated development in shared mobility. To get the designed chassis which is 600kg in weight, 1.8m in length with 15kW motor and 7.68kWh lithium battery for meeting the requirements of 72kph of top speed and 70km of the range, to be implemented in different scenarios, researchers and designers adopted plug-and-play model to load with necessary ICT devices whenever the chassis needs to be transformed into surveillance car, logistic delivery fleet, or urban personal last-mile mobility. Scenario innovation derive system requirements

2. Scenario Innovation Derives System Requirements

The 3 potential scenarios of the safe, smart chassis discussed green in this paper are for the utilizations of surveillance car, logistic delivery fleet, and urban personal last-mile mobility.

- Surveillance car

GSSLV can be used in outdoor surveillance fleet in closed areas. Compared to the existing 2-wheel motorcycle for surveillance fleet use, 4-wheel GSSLV provides shelter for the security guards. Especially lots of rain and typhoon in Southeast Asia countries, GSSLV could give more safety protection to the security persons on duty. In addition, 4-wheel GSSLV has no emission, and become a clean shuttle from outdoor to indoor. Since the part patrol routes are usually fixed, GSSLV could be ICT modules embedded, with autonomous driving function. It will improve the overall efficiency and save the manpower. The potential application users could be the property management firms, logistics firms, and other companies with large factory or park area.

- Logistic delivery fleet

Micro Mobility use case for mail parcel service. Due to the convenience of Internet communication, the declining mail volume become a trend in many countries. Therefore, these post offices face the revenue issue when they need to replace the postal vehicles. They take the electric vehicles as consideration, once there is the subsidy for purchasing EV from the government. Another reason is the stringent emission rule for fleet operation in urban area. The postal fleet has fixed route, and needs to shuttle in the narrow street. Small sized, Low-speed EV is suitable for such demands.

- Urban personal last-mile mobility

Last-mile concept from the public transportation drives the needs to personal mobility. In the background of aging issue, the development of personal mobility for elder people moving service is getting important. Based on JARI(Japan Automobile Research Institute, 2015)report, there are 2 major points for the elder people driving needs: visual, and steering flexibility. Therefore, the vehicle features for the elder people use should focus on micro EV, with accident prevention, and driving assistance.

2.1. Demands of potential scenarios

There are 3 potential scenarios applications, such as for surveillance, for logistic delivery and for last mile personal mobility in urban area. MIRDC provides an open innovation chassis for multi-purpose smart light green vehicles. Below is the common requirement on technology for these 3 applications at green, safety and smart issue respectively.

2.1.1. Green (EV)

In this green and light vehicle, lithium battery is the necessity to meet both in size and weight. Battery capacity and specification be with min.100 Ah, min. 6.0 kWh and 72 V are mostly meet the scenarios. Besides, the efficiency of power train should be more than 90 % for the power train range 5-15 kW.

2.1.2. Safety (Structure)

There is no crashworthiness regulation for this kind of Green Safe Smart Light Vehicle nowadays. But considering the quantity increasing for the near future, Euro-NCAP tends to set up a new protocol to L6 or L7 Quadricycle. The frontal impact at specific speed could be the minimum requirement. In order to reduce the weight and ensure the durability, multi-materials structure used in steel and aluminum seems to be a good solution. In addition, the modular structure and slip plane/joint design bring wider adjustable characteristic in wheelbase/track for meeting different scenarios use.

2.1.3. Smart (ICT)

Due to the lower vehicle speed for these 3 scenarios, all the autonomous related sensors and components would not need to be as high operation speed or resolution as the sedan segment specification. In Taiwan local government regulation, it is permitted to run less than 20 km/hr. on road for autonomous vehicle. All the ICT or Advanced Driver Assistance Systems (ADAS) related smart functions can be equipped in these vehicles.

3. Mobility on Demand - The Designed Green, Safe Smart, and Light Vehicle (GSSLV) Chassis

3.1. System requirements responding to the demands of potential scenarios

3.1.1. Green (EV Battery)

According to the current situation of the vehicle industry, the electric vehicles launched by many electric vehicle manufacturers are mostly “twin” vehicles manufactured by making use of the existing internal combustion engines, and equipped them with high-power motors and high-capacity batteries after partial modification and matching, rather than the optimized chassis designed especially based on the characteristics of electric vehicles. The reason for this is that, the R&D costs of new-type electric vehicles are high, and that electric vehicles have not yet become the mainstream market vehicles. In order to meet their economic benefits, most manufacturers of electric vehicle will not invest a large amount of money, but instead, they will choose the lower-cost development modes. This paper explained the two major characteristics of GSSLV in its body structure design that helped to reduce its development costs: 1. Application of Slip Joint / Slip Plane; 2. integrated design for chassis and battery box.

The GSSLV model/type, as mentioned in this paper, is designed in accordance with the European regulations L7, and the body structure is designed using the Space Frame construction method. In the European regulations, L7 model/type of vehicle does not need to go through the crash test. But the power of L7 vehicle can be up to 15kW. Depending on the electric motor powered by the battery, the speed of L7 vehicle can reach up to 60km/hr or so. Thus, in case of a lack of properly structural design, there might be substantial doubts about the driving safety of this level of vehicle models.

In design, the upper body of GSSLV is mainly made of aluminum alloy materials to achieve the effect of reducing the center of gravity; the underbody of GSSLV is mainly made of high-strength steel materials to achieve sufficient body strength. The materials are so distributed to give consideration to both lightweight and high safety. By making use of structural module design and special Slip Plane / Joint design, it has expanded the advantages (quick and easy changes in design) and solved the disadvantages (poor accuracy & precision of assembly) of Space Frame.

By utilizing the cross-section tubular structure to adjust the position of pipe fittings in a single direction, the Space Frame itself is a large number of pipe joint structures. As the proportion of manual assembly of this structure is higher than the Unibody, there will be a lot of problems on precision/accuracy deviation from the tube-to-tube connections easily caused by deformation of materials or other factors in the welding process. Since the tube-to-tube connections are mostly the key areas of Load Path, easily leading to structural damage, the Slip Joint/Plane should be designed to withstand the structural stress and absorb the deviation between pipe assemblies. The initial concept of Slip Plane is: To facilitate the positioning and joining of panel and pipe fitting and reduce the use of the positioning fixture. This design is based on the concept of extruded aluminum tube. The profile section of extruded tube contains a clear rib-like structure. The sliding sleeve structure of Slip Plane can follow the rib-like structure for one-dimensional scale slip, so that the alignment accuracy of overall assembled structure is simplified into one-dimensional size control before welding, in order to reduce the time and cost required for adjustment of assembly tolerances and simplify the fixture design. The precision of assembly can be controlled within ± 1.75mm / 3,000mm. The thickness of sliding sleeve of Slip Plane can be used for strengthening the strength of extruded aluminum tube joint, and making up the weakened effect of aluminum alloy materials after welding. In addition to strengthening the strength of body, the rib-like structure can be used to produce a variety of purposes, such as the same material welding, different material riveting, lap plate, drilling and other purposes, plate lapping, drilling lapping and other purposes, without welding or drilling, thus affecting the strength of extruded aluminum body.

The design used a large number of aluminum alloy (red) and high-strength steel (yellow) materials. So, in order to take into account the joint application position and different strength requirements, and enhance the lightweight benefits of Space Frame L7 chassis structure, the Slip Joint steel-aluminum joints are used for the joint between the different materials. The application of geometric appearance design and compound joint technology is aimed to solve the limits on the combination of different material structures of Space Frame, and reduce the formation of intermetallic compound for welding of different materials. The value of lapping tensile force at the joint of steel-aluminum Space Frame is ≧ 300Kgf or above.

In order to ensure a certain endurance mileage, an electric vehicle is often required to carry a 100 kg battery module. Due to the heavy weight of battery, the battery module must be fixed with the structure being of enough strength. The common practice is: To connect the battery box to the body chassis or rear trunk. However, this assembly method will produce at least the following disadvantages: 1. Very low chassis; 2. over-weight of rear; 3. repeated design for the overall structure of chassis. To solve this problem, the GSSLV integrated the chassis and battery box. The battery box is designed to be pushed downward and removed, and is made of aluminum alloy (red) and high-strength steel (yellow) structural materials. Especially, the application technology of composite metal electromagnetic shielding shell is applied to the upper cover of battery box. The development of the composite metal electromagnetic shielding shell can effectively reduce the electromagnetic interference on the battery module, to achieve an electromagnetic radiation value of ≦65dBμV/m. The external main structure of the battery box is made up of extruded aluminum alloy tubes. The four groups of high-strength steel tubes then go through the main body to connect to the main body. This design improved the body strength and strengthened the collision safety of vehicles. Head-on collision is the most frequently occurring accidents, which may be represented by two kinds of arrows, especially indicated in Fig. 6, respectively, i.e. a solid arrow indicating the main force path and a dashed arrow indicating the accessory force path. In the process of collision, as a result of the small body of GSSLV, resulting in the small structural collapse space, there is no difference between the main beam and the secondary beam as adopted by the common passenger vehicle. In order to increase the safety of vehicle body, the design hoped to expand the surface withstanding the impact force, so that the force can be dispersed in the front of the vehicle body along the preset path. Most of the force will be transmitted along the main path. It can be noted that, the aluminum alloy structure of battery box is not planned as the path structure transmitting the force, in order to improve the safety of battery.

3.1.2. Safety (Crash FVMSS 208 and ISO 2631)

The chassis structure already features the following technologies:

- Passing the ISO regulations on riding comfort
  According to the regulations of ISO 263, when the vehicle is traveling on the general road surface, the root mean square value of acceleration and the comfort evaluation index shall be as shown in Table 1 below. After the field test, the acceleration of lightweight chassis traveling on the general road surface is less than 0.63 m/s2, which will be evaluated as not uncomfortable to a little uncomfortable levels.

Table 1: Table of the comfort evaluation indexes (ISO 2631-1)

Root mean square value of acceleration	Index
$<0.315\ m/s^2$	Not uncomfortable
$0.315\ m/s^2 \sim 0.63\ m/s^2$	A little uncomfortable
$0.5\ m/s^2 \sim 1\ m/s^2$	Slightly uncomfortable
$0.8\ m/s^2 \sim 1.6\ m/s^2$	Uncomfortable
$1.25\ m/s^2 \sim 2.5\ m/s^2$	Very uncomfortable
$>2\ m/s^2$	Extremely uncomfortable

- Passing the fatigue durability (100,000 km) simulation analysis verification of body structure
  After the field test, data acquisition, analysis & filtering of data, multi-body dynamics simulation analysis, stress simulation analysis and fatigue simulation analysis, the fatigue durability (100,000 km) simulation analysis of body structure has been completed. According to the results, it can be estimated that, under the general conditions, the body structure can withstand at least 179,491 km without fatigue damage.(Fig 1)

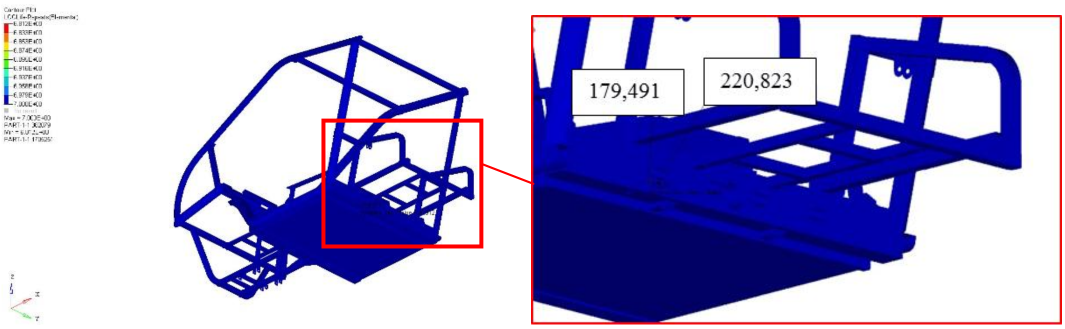

Fig. 1 : Fatigue durability simulation analysis results (km)

- Passing the fatigue durability (50,000 km) bench test verification of body structure
  After the field test, field data acquisition, simulation analysis, equivalent analysis and equivalent bench test of body structure, the fatigue durability (50,000 km) bench test for body chassis platform has been completed. There is fatigue damage to some parts. After reinforcement, the body structure has passed the fatigue durability (50,000 km) bench test verification.(Fig.2)

Fig. 2: Fatigue durability bench test

- • Passing the 48 km/h head-on collision rigid wall simulation analysis verification of body structure
  There are no specific regulations for the collision detection of L7 model. With reference to the general vehicle collision regulations (FMVSS 208), the simulation of frontal impact with a rigid wall is established at a speed of 48 km/h. According to the collision simulation analysis results, it is suggested that the vehicle side structure is increased; there is no obvious invasion of the safety space of passenger compartment after the modification; and the safety of passengers can be protected after the collision. (Fig.3 and Fig. 4)

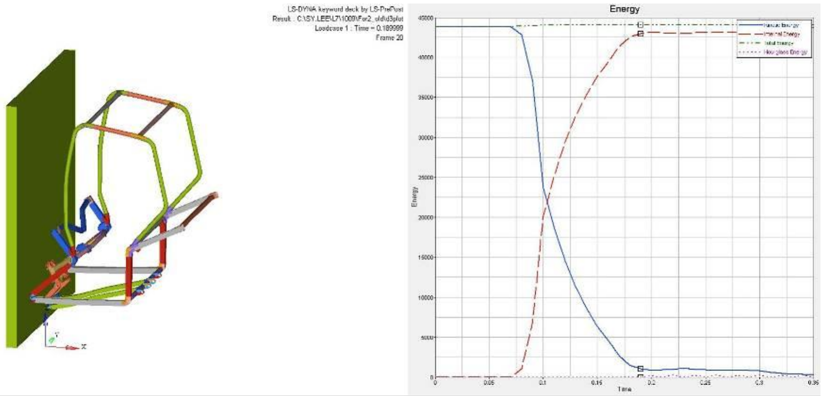

Fig. 3: Collision simulation analysis

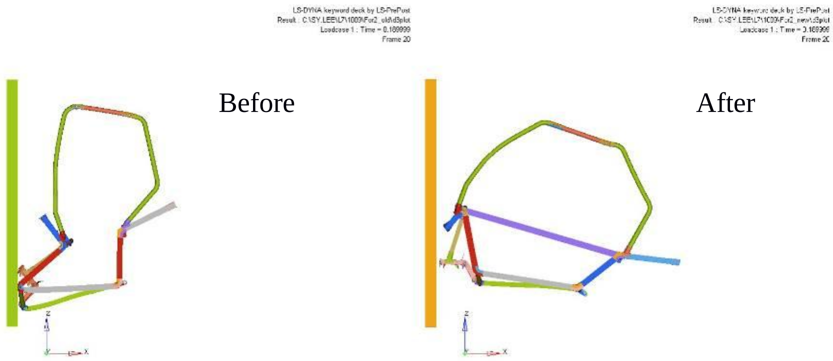

Fig. 4: Collision simulation analysis results after the modification

3.1.3. Smart (ICT plug and play)

Without a sound EMI and EMC electromagnetic compatibility protection design for the power system and charging system of electric vehicle, the electronic parts will be interfered; or, in severe case, it will lead to the loss of control or brake failure of the vehicle, affecting the entire safe operation capability of the vehicle

In accordance with the relevant laws and regulations on the limitation to the electromagnetic interference successively developed by the international organizations, if their electromagnetic interference fails to meet the standards, the product cannot be manufactured or imported. One of the methods for solving the problem on electromagnetic interference is the so-called electromagnetic shielding, where the shielding shell is made of the conductive or magnetic materials, and used for surrounding the electromagnetic wave emission source, inhibiting the electromagnetic wave radiation and blocking the electromagnetic wave from the outside, thereby improving the anti-interference performance (immunity) of electronic products. When the electromagnetic wave is going through the shield, the energy attenuation should be referred to as the shielding effect (SE). The factors affecting the shielding effect are as follows: Shielding materials, shielding thickness, shielding frequency, distance between the shield and the interference source, etc. The single layer shielding material structure is mostly adopted for the shielding design in the market. With the development of composite material rolling process technology, the multi-layer shielding material structure will play a more important role in the material selection and structural design. In this case, considering the frequency band to be shielded at 30MHz ~ 1000MHz, and taking into account the requirements for light weight, high strength, heat dissipation, good shielding effect and convenient processing, the electromagnetic shielding shell is designed to be made of aluminum/copper layered composite materials.

From the theoretical analysis, it is known that, in order to shield the high-frequency and low-frequency magnetic fields at the same time, combined with the characteristics of the different materials (e.g. light weight, shielding property, structural property, etc.), the shielding shell can be designed to introduce the high-conductivity materials to produce the eddy current reverse magnetic field, offset the magnetic interfering field, allow the high-permeability material to constitute a low reluctance path, and allow most of the magnetic fields to be concentrated in the shield. Therefore, relative to the single-layer shielding structural materials, the multi-layer composite metal shielding structural materials can achieve more advantages through a reasonable optimization design as follows: The shielding shell is made of sheet metal parts; the plate is designed to avoid the line set and match with the appearance of electronic parts; the aluminum is used as the external material to achieve the lightweight and beautiful appearance; the copper is used as the internal material to directly block the electromagnetic waves (Fig. 5 & 6).

Fig. 5: Power module shielding shell

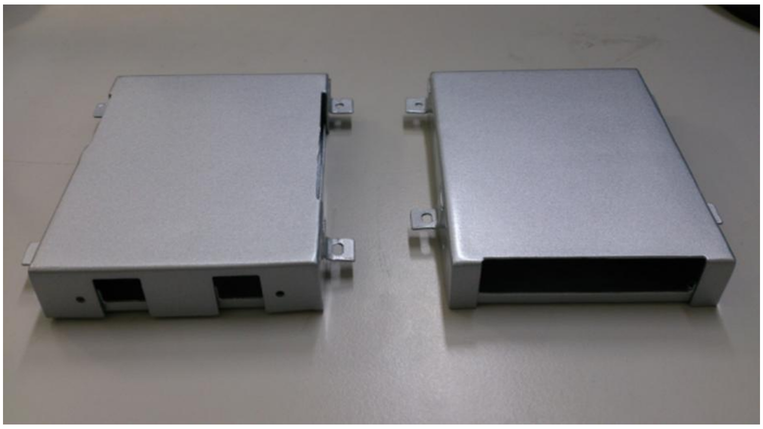

Fig. 6: Battery module shielding shell

In accordance with the provisions as stipulated in the regulations on electronic equipment on VSCC561 vehicle, the electromagnetic radiation value of vehicle must be: ≦65dBμV/m (400~1,000MHz). However, the acceleration test results of the SGLV vehicle show that, before shielding, the electromagnetic radiation value of power module is up to 140dBuV/m or so; after the installation of the aluminum/copper layered composite electromagnetic shielding shell, the radiation value dropped to about 20dB; after shielding the power module, the radiation value is up to about 1dB in line with the provisions as stipulated in the regulations on electronic equipment on VSCC561 vehicle (Fig. 7).

Fig. 7: Actual installation of the shielding shell

In accordance with the requirements for the high performance and safety of electric vehicle industry, the electromagnetic compatibility of electric vehicle must be tested before the vehicle can be driven on the road. As electromagnetic interference is very harmful to electric vehicles, the importance of solving the problem on electromagnetic compatibility is of considerable practical significance.

3.1.4. Niche of the designed chassis

The schematic diagram of the Green Safe Smart Light Vehicle (GSSLV) chassis platform self-developed by the Metal Industries Research & Development Center (MIRDC) is shown in Figure 8. The size of SGLV is 2,478 x 1,301 x 1,578 mm (L x W x H); distance between shafts: 1,800 mm; total weight of vehicle: 600 kg; number of passenger: 2 people; power of motor: 15 kW; energy consumption of lithium battery: 7.68 kWh; maximum speed: 72 km/h; endurance mileage: 70 km. For detailed specifications, please see Table 2 below.

The SGLV's current characteristics can be divided into three major categories: (Fig. 8)

- Designed for the needs of the intelligent and aged society, including: Advanced driving assistance system (ADAS); auto-detection of driver's physical status; and rear door accessibility design (for easy wheelchair access);
- Conform to three EU regulations, including: 97/24/EC - Electromagnetic Interference (EMI) Protection Test; 93/14/EEC - Brake System Test; and 95/01-I / EC - Maximum Speed Test;
- Design and certification of body structure, including: 48 km/h forward collision simulation analysis; comfortability and ergonomics conforming to the ISO standards and European regulations L7; body structure passing the 100,000 km fatigue simulation analysis and 50,000 km bench fatigue verification, etc.

Figure 8: Figure for smart green light vehicle

Table 2: The Specifications of smart green light vehicle

Item	Specifications
Length/Width/Height	L 2,478mm / W 1,301 mm /H 1,578 mm
Wheelbase	1,800 mm
Ground clearance	180mm
Assembly tolerance	< ±1.66 mm / 3,000 mm
Structural materials	Aluminum：52%、Steel：45.7%、Others：2.3%
Curb weight	383kg (Without Batteries)
suspension	F-Macpherson、R-Trailing arm
Tyres front/rear	165/55 R14
Reduction ratio	1：8.75
Battery/BMS	Lithium ion 7.68kWh / Whetron BMS
Motor/Controller (AC-12/Curtis)	15 kW (Front-wheel drive)
Top speed	72 km/h
Acceleration	0 ~ 60 km/h @ 10 sec
Climbing capability	> 25% @ 25 km/h
Driving distance	≧70 km

3.2. Pilot project for surveillance car

After the completion of test for integration interface of open ICT module, the carrying functionality of SGLV vehicle was tested. Along with the manufacturers, closed-park patrol inspection was conducted, and relevant commissioning data was collected.

Before commissioning, because of the more complex electrical environment on the SGLV vehicle, the power supply and signal for integration interface of open ICT module are required to complete the planning and implementation. The architecture diagram of electrical system of SGLV vehicle is shown in Fig. 9 below. In order to make sure that the integration interface of open ICT module can be erected on the SGLV vehicle in the best operating environment, before the integration interface of open ICT module developed for this plan is erected on the real vehicle, its module configuration and control strategy were checked to be consistent with the expected effect, and that the vehicle-related information can be collected during routing inspection, including the power and ICT module-related information, and that the simplified statement of routing inspection points can be made for message feedback, so as to really grasp the relevant problems. The schematic diagram of erection of related ICT module on the integration interface of open ICT module is shown in Fig. 10. The photo of field operation is shown in Fig. 11.

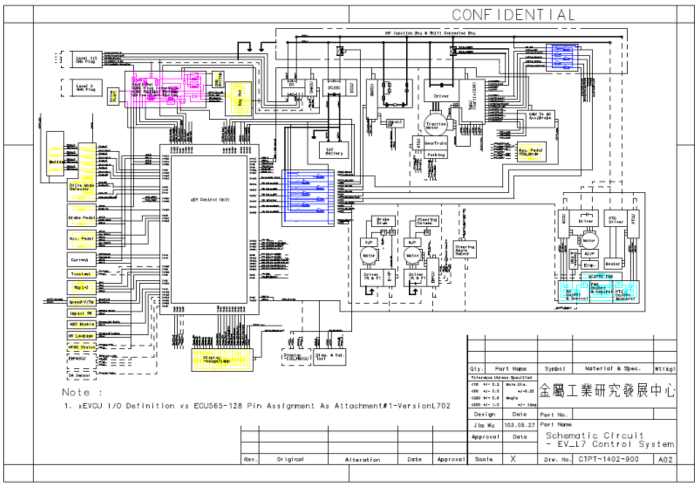

Fig. 9: Architecture diagram of electrical system of open chassis

Fig. 10: Application to the erection of open chassis platform and related ICT module on the open ICT module integration platform

Fig. 11: Demonstration in Luzhu Science Park

4. Conclusion

MIRDC has built up the plug and play micro EV with GSS running chassis。This niche chassis platform has been linked to the domestic chassis components companies. It will assist the manufacturers to enhance the ability from the chassis key module design, to the structure safety development, which increases their competitiveness to the international supply chain.

The pilot project of surveillance car has been launched in Luzhu Science Park. This operational experience can be accessed to the related scenarios, new business models, and adopted to other fields for the verification and display, such as the playground, the local science park, or campus.

MIRDC has worked together to connect with global stakeholders. A pilot open innovation platform of shared mobility and its cluster value chain is built up through the collaboration with APEC Policy Partnership on Science, Technology and Innovation (PPSTI), a scenario innovation competition and policy dialogue are held to integrate comments on sustainable development of shared mobility from government, academia, and private sectors.

References

[1] J.J. Romm, The hype about Hydrogen, ISBN 1 55963 704 8, Washington, Island Press, 2005

[2] P. Van den Bossche et. Al., SUBAT, an assessment of sustainable battery technology, Journal of Power Sources, ISSN 0378 7753, 162(2006), 913-919

[3] EVS30, http://www.EVS30.org, accessed on 2016-11-06

[4] Green Car Congress, http://www.greencarcongress.com/, accessed on 2016.8

[5] Global Mobility Service, http://www.global-mobility-service.com/，accessed on 2015.3

[6] Nikkei Automotive, http://techon.nikkeibp.co.jp/AT/magazine/, accessed on 2015.9

[7] International Standard, ISO 2631-1, 2010

[8] ARTC, https://www.artc.org.tw/chinese/03_service/03_02detail.aspx?pid=58, accessed on 2009

[9] Federal Motor Vehicle Safety Standard 208, http://www.nhtsa.gov/cars/rules/import/FMVSS/#SN208, 1998

[10] http://taismeoip.apec.org

[11] Saffa Riffat, Richard Powell and Devrim Aydin, *Future cities and environmental sustainability*, Future cities and environmental sustainability, ISSN: 2363-9075,

[12] Jornsen Reimpell, Helmut Stoll, The Automotive Chassis: Engineering Principles, Society of Automotive Engineers Inc; 2 edition，2001。

[13] Jornsen Reimpell, Helmut Stoll and Jurgen W. Betzler , The Automotive Chassis (Second Edition) Engineering Principles, Elsevier Ltd, 2000.

[14] Peter Holdmann , Frank Berger, Kinematics and Compliance of Sports Utility Vehicles, SAE Technical Papers 2001-01-0491, 2001.

[15] C. C. Chan, K. T. Chau, Modern electric vehicle technology, 2008.

[16] Jason C. Brown, A. John Robertson, Stan T. Serpento, Butterworth-Heinemann, Motor vehicle structure: Concepts and Fundamentals, 2002

[17] Mounir M. Kamal, and Joseph A. Wolf, Modern Automotive Structural Analysis, 1982

Authors

Ping-Huei SHU

Professor

Department of Vehicle Engineering

National Taipei University of Technology

Email: jphshu@yahoo.com

Yu-Ting LIN

Engineer, Vehicle Structure & System Section

Metal Processing R&D Department

Metal Industries Research & Development Centre(MIRDC)

Email: ek.lin@mail.mirdc.org.tw

Wan-Ting HUANG

Project Manager

Office of Cross-Strait Exchange

Industrial Research Technology Institute(ITRI)

Email: elsie.h@itri.org.tw

Jui-Wen YANG

Industrial Analyst

Industrial Research Section, Planning & Promotion Department

Metal Industries R&D Centre(MIRDC)

Email: monicayang@mail.mirdc.org.tw

Dr. Michael Jinn –Feng JIANG
Planning &Promotion Deputy Director
Industrial Research Section, Planning & Promotion Department
Metal Industries R&D Centre(MIRDC)
Email: jfiang@mail.mirdc.org.tw

Sheng-Yun LEE
Engineer
Vehicle Structure & System Section, Metal Processing R&D Department
Metal Industries R&D Centre(MIRDC)
Email: sylee@mail.mirdc.org.tw

Nai-Chi SHIUE
Senior Industrial Analyst
Industrial Research Section, Planning & Promotion Department
Metal Industries R&D Centre(MIRDC)
Email: nc_shiue@mail.mirdc.org.tw

Pao-Hsien HSIEH
Chief, Vehicle Structure & System Section
Metal Processing R&D Department
Metal Industries Research & Development Centre(MIRDC)
Email: evan@mail.mirdc.org.tw

Chih-Ming CHANG
Deputy Chief
Vehicle Structure & System Section, Metal Processing R&D Department
Metal Industries R&D Centre(MIRDC)
Email: c-ming@mail.mirdc.org.tw