

Invited Paper

Bikeinformatics: An Introduction of Informatics to the Motorcycle Researches and the Development of New Generation Motorcycle-based Personal Vehicles

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Abstract: In this paper, we describe the current situation of the motorcycle industry, the world's markets, and the trend of motorcycle researches. The purpose is to promote researches and developments of motorcycles so that motorcycles become safer and more convenient, and people will obtain good user-experiences (UX) with their motorcycle in their life. We summarize the current research issues and the current social issues about motorcycles, and then we introduce a solution for them with informatics and its related science and engineering. To make a motorcycle safer and to enhance its mobility, it is essential to investigate the motorcycle dynamics. The motion of a rider is also essential, and it affects the motorcycle motion, whereas the motion of a car driver seldom affects the car motion. It is because the weight of a rider is large enough, comparing to the weight of a motorcycle, and a rider usually moves widely to operate the motorcycle. In order to investigate the dynamics of the motorcycle system, which consists of a motorcycle itself and a rider, it is required to obtain appropriate sensing data of both the motorcycle and the rider to improve the knowledge of the dynamics by the data. Such data and knowledge can be applied to other applications and services such as sensing road traffic conditions. In this paper, we introduce the concept of the research project, Bikeinformatics, and the capability of GNSS precise positioning to append adequate labels to measured data with low-cost sensors.

Keywords: motorcycle, vehicle dynamics, survey of a research area, data probing with vehicles, crowdsensing system, intelligent transport systems (ITS)

1. Introduction

Motorcycles seem to be regarded as ordinary people's vehicles or transient vehicles until they own cars in developing countries. In the developed countries, motorcycle seems to be regarded as a hobby-use vehicle or a vehicle for enthusiasts. As compared with car drivers, motorcycle riders are likely to be injured at a traffic accident. It takes more time for a motorcycle rider than a car driver to wear protective gear such as a helmet and gloves when starting riding. The bad weather like rain, snow, and coldness may decrease a rider's comfort quickly. These reasons are enough for people not to be interested in a motorcycle when they have a car.

On the other hand, since most of the motorcycles are smaller, lighter, and lower mileage than that of cars, motorcycles have fewer negative effects on road traffic, road surface, and its environment. They are economical to maintain the road infrastructure. In the future, in emerging countries in Asia, when people changed their motorcycle to cars, transportation in a city might collapse, and the maintenance cost of the road infrastructure would become enormous. Motorcycles have many useful features. It is favorable to utilize more motorcycles in order to improve the efficiency of grand transportation with cars, buses,

and trains.

A reason why people are not willingly choosing a motorcycle as their vehicle is because few ADAS (advanced driver assistance systems) and few ITS (intelligent transport systems) for motorcycle riders have been developed, or they have been delayed whereas many ADAS and ITS for car drivers, e.g., an adaptive cruise control system and an emergency brake system, have been developed. Since the body structure of a motorcycle is more complex and its vehicle dynamics is different from a car, it is difficult to adopt such ADAS directly to motorcycles. Additionally, since the retail price of a mainstream motorcycle is generally much lower than a mainstream car, the research and development cost for ADAS for motorcycle riders is also lower in this situation. Despite this, there is little public support for researches and developments for ADAS for motorcycle riders. Most of the fundamental researches about motorcycles and such personal vehicles have been worked inside the motorcycle manufacturers, and there are few academic/public researchers about motorcycles. Most of such research achievements are closed, or the number of achievements might be limited and not structured.

In this paper, we describe the current situation of the motorcycle industry, the world's markets, and the trend of motorcycle researches. Then, we discuss how motorcycles are able to be improved, what researches and developments for motorcycles will be needed, and how informatics can help such researches and development.

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Table 1 Annual sales of motorcycles in the world (2009) [2].

Area	# of sales [million] (% of the world)	JPS*
Asia	39.61 (80.2%)	51.8%
Japan	0.43 (0.9%)	89.2%
Europe	2.13 (4.3%)	31.2%
North America	0.84 (1.7%)	52.3%
C. and S. America	3.16 (6.4%)	60.2%
Total	49.40 (100%)	48.9%

*JPS indicates the area share of Japanese manufacturers.

Table 2 Market size of motorcycles and cars (2017) [2].

	Motorcycles	Cars
Annual Sales in the world	59 million vehicles	97.3 million vehicles (73.5 million without buses and trucks)
World share of Japanese manufacturers	46.0%	26.5% [4], [5]
Industry size of Japanese companies	3.4 trillion JPY [6]	68.0 trillion JPY [7]

2. Motorcycles in the World

2.1 Motorcycle Markets

2.1.1 Number and Amount of Motorcycle Sales

The number of annual sales in the world in 2017 is 59 million motorcycles [1]. The peak of annual motorcycle sales is marked in 2011, and the number is 64.11 million. For several years, the number of annual sales is around 60 million motorcycles. This number is large enough, whereas the number of annual sales is 97.3 million cars [2]. There are many motorcycle users, and motorcycles are one of the major transportations in the world. People in developing countries prefer to use motorcycles because the price of a motorcycle is much lower than a car, and motorcycles are more suitable for unpaved roads in the countries. Asian countries, especially south and south-east Asian countries, occupy an 80 percent share of the world's motorcycle sales, as shown in **Table 1**. **Table 2** shows the market size of motorcycles and cars. Note that we currently do not consider electric scooters and electric bicycles as motorcycles in the statistics in this paper. The number of annual motorcycle sales, including electric motorcycles in the world, will be much larger than cars.

Table 3 shows the number and amount of annual sales of each major motorcycle manufacturers surveyed by the author. The target survey year depends on each manufacturer: 2015 to 2018. The numbers are according to the web site of manufacturers or market survey companies. The amount of sales of every manufacturer is converted into Japanese Yen. Note that we have tried to ensure accurate estimation of each amount of sales, but some of them may include the amount of other business of each company. Additionally, there are at least six other Chinese motorcycle manufacturers (the number of their sales are ranked the 4th to the 10th in China) [3], but they are eliminated from the list because of lack of information.

The number of sales tends to be affected by the Chinese and Indian markets, and the top 10 manufacturers are only Japanese, Indian, and Chinese companies. It is because 80 percent of motorcycles are sold in Asian countries.

2.1.2 Japanese Market

In Japan, the number of annual motorcycle sales dips to 335

Table 3 Annual number and amount of Sales of Motorcycle Manufacturers.

	Manufacturer (country)	Amount [JPY]	Number [unit]	Year
1	Honda (Japan)	2,038.7B	19.55 M	2017
2	Yamaha Motor (Japan)	1,045.2 B	5.38 M	2017
3	Harley-Davidson (U.S.)	628.7 B	456 k	2018
4	Hero MotoCorp (India)	484.0 B	7.50 M	2017
5	Bajaj (India)	352.0 B	3.40 M	2015
6	Kawasaki Motors (Japan)	331.6 B	494 k	2017
7	Haojue (China)	est. 300 B	2.10 M	2016
8	BMW Motorrad (Germany)	258.6 B	164 k	2016
9	Suzuki (Japan)	246.4 B	1.58 M	2017
10	TVS (India)	242.0 B	3.47 M	2017
11	Zongshen (China)	220.0 B	1.10 M	2016
12	Lifan (China)	189.3 B	1.10 M	2016
13	Loncin (China)	180.6 B	1.10 M	2016
14	Piaggio & C. S.p.A. (Italy)	167.8 B	552 k	2017
15	KTM (Austria)	166.3 B	191,196	2017
16	KYMCO (Taiwan)	149.6 B	560 k	2017
17	Royal Enfield (India)	137.4 B	820 k	2017
18	SYM (Taiwan)	117.0 B	680 k	2017
19	Ducati (Italy)	92.0 B	55,871	2017
20	Triumph (UK)	72.3 B	63,404	2017

B denotes billion, M denotes million, and k denotes thousand.

The exchange rate of each currency as of February 2019:

110 JPY/USD, 125 JPY/EUR, 145 JPY/GBP, 16 JPY/CHY and 1.6 JPY/INR.

thousand in 2018 after peaking in 1982 with 3.28 millions [2]. Most of the decrease is because of the number of 50 cc motorcycles, and the number of motorcycles with bigger than 125 cc engine has been increased for 28 years [1].

A reason why the decrease of 50 cc motorcycles in Japan is that mini-sized cars with a 550 or 600 cc engine, as known as "Kei-car" in Japanese, was developed in the early 1980s and have got popular among women in countrysides. They have changed to own a mini motorcycle to a mini-sized car.

Another reason why the decrease of small motorcycles in Japan is that people overconcentrate in the urban area where other grand transportation is extremely convenient. People in such an urban area still used motorcycles to avoid heavy road traffic until 2006. However, strengthening control over illegal parking in 2006 and the financial crisis in 2008 have affected to the decreasing of small motorcycles as commuters in the urban area. The number of motorcycle sales is affected by such road traffic policy.

The number of motorcycles in operation (in other words, the total number of motorcycles that have currently been provided for use) in Japan is 11.5 million (including 7.5 million 50 cc motorcycles), whereas that of cars is 61 million. The number of motorcycles is not small yet.

Since the number of small motorcycle sales is much decreasing, on the other hand, the number of ordinal motorcycle sales is still increasing, the money amount of motorcycle sales is not decreasing.

2.1.3 Emerging Countries' Market (Mainly Asian)

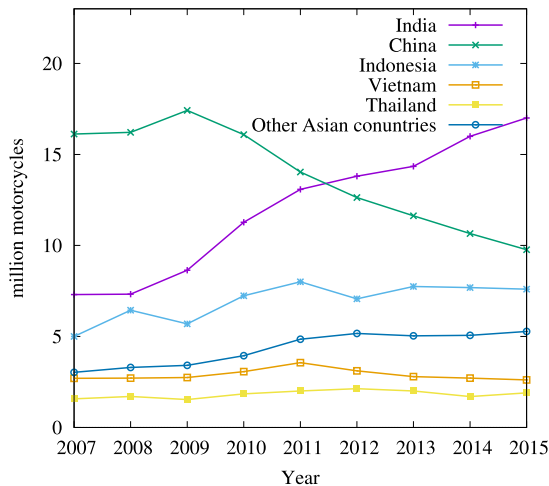
Asian countries, especially south or south-east Asian countries, are the main market of motorcycles. Eighty percent of motorcycles in the world are sold in such Asian countries, and most of them are produced there.

Motorcycles are said to become popular in a country where GDP per capita exceeds 1,000 to 3,000 USD. The main reason is that the price of a motorcycle is not high. Additionally, a motorcycle is more suitable for unpaved roads, and it has got popular

Table 4 Motorcycle production or sales in emerging countries [2].

(a) Number of Motorcycle Production in China (2013)		(b) Number of Motorcycle Sales in India (2014)		(c) Number of Motorcycle Production in Brazil (2013)	
Engine size	# of production	Body size	# of sales	Engine size	# of production
< 90 cc	1.84 M	Wheel size ≤ 12 in.	4.10 M	< 50 cc	40 k
100 to 110 cc	5.23 M	Wheel size > 12 in.	9.88 M	51 to 150 cc	1360 k
125 cc	8.31 M	Moped (< 75 cc)	0.78 M	151 to 300 cc	140 k
150 cc	4.26 M			301 to 450 cc	2 k
250 cc	0.78 M			450 cc <	50 k

M means million.
k means thousand.

**Fig. 1** Motorcycle demand in Asian countries [10].

in countries where the road infrastructure is still developing. In countries where GDP per capita exceeds 10,000 USD, the road infrastructure is almost developed, and people start to change to cars as their primary vehicle.

Motorcycle manufacturers try to develop new markets in African countries, to enhance the market in emerging countries and to maintain the market not to shrink in developed countries [8]. As one of the particular cases, Taiwan is well developed, and GDP per capita is more than 20,000 USD, but people still use motorcycles as their main vehicle [9]. Taiwan is a similar situation to former Japan. In Taiwan Motorcycles, especially scooters, are still popular not only for men but also for women because there are no kei-cars not like Japan. Although the population density of Taiwan is the 2nd highest in the world (excluding the city-states), the traffic system in Taiwan is adjusted to motorcycles, and motorcycle riders can avoid heavy traffic jams.

Figure 1 shows the demand of motorcycles in Asian countries [10]. In China, the number of sales of conventional motorcycles with an internal-combustion engine is decreasing because of regulations to prevent air pollution in city areas and because people in the urban area changed their motorcycles to cars this decade. India is now a growing motorcycle market.

Although the big decreasing in China, the number of sales in the world is not decreasing. The money amount of sales is increasing due to increasing the price of the motorcycles and economic growth of such Asian countries.

Table 4 shows the popular size of motorcycles in emerging countries as the main motorcycle market. Motorcycles with less than a 150 cc engine are mainstream there. According to Honda in Indonesia, a mainstream motorcycle of local models has a

110 to 150 cc engine, and its price range is between 1,000 USD to 3,000 USD [11]. Some premium models priced at more than 5,000 USD are also available.

The global models, mainly for developed countries and wealthy class, are offered between 10,000 USD to more than 30,000 USD [12].

2.1.4 Chinese Market and Small Electric Motorcycles

In China, most people have used motorcycles as the primary vehicle. The population is 1.39 billion in 2017, the number of all motorcycles (including electric scooters) in operation is 280 million in 2016, and the penetration of all motorcycles (including electric scooters) is 20.1% [13]. These motorcycles consist of 200 million electric scooters (about 14%) and 80 million conventional motorcycles with an internal combustion engine (about 6%). The number of annual internal-combustion-engine-motorcycle sales is currently 8 million, as shown in Fig. 1, and it is half after peaking in 2008. On the other hand, the number of annual electric-scooter sales is currently 34 million. The largest country of internal-combustion-engine-motorcycle sales is now India, but China is still the largest of motorcycle sales of including electric scooters.

Major reasons why such electric scooters are popular in China are as follows [13]:

- A license plate is not needed for an electric scooter, whereas it is costly to get a license plate for an internal-combustion-engine-motorcycle in a big city (An electric motorcycle also needs a license plate from 2019).
- No helmet requires while riding an electric motorcycle.
- There are many charging stations for electric motorcycles enough.
- No license is needed to ride an electric motorcycle.
- Motorcycles with an internal-combustion engine are restricted to enter big cities by regulations.

For ordinary people in urban areas, an electric-bicycle sharing business (e.g., mobike [14]) is getting popular from 2016. No Chinese electric motorcycle manufacturers are listed in Table 3.

In countryside areas, internal-combustion motorcycles are still popular both for personal and for business use.

2.1.5 Indian Market

India's GDP per capita is about 2,000 USD, and it is lower than China's 8,600 USD. India is a country where motorcycles become popular. The number of annual motorcycle sales in India is about 20 million, and it is the largest in the world. Indian motorcycle manufacturers, e.g., Hero MotoCorp, Bajaj, TVS, and Royal Enfield, are growing significantly.

Since India has not developed as well as China yet, air pollution has not become a severe problem. Although the number

Table 5 Number of owned motorcycles and GDP-per-capita.

country	population	penetration	# of motorcycles in operation (A)	# of annual sales (B)	(A)/(B)	GDP per capita
China (electric motorcycle)	1.39 B	14%	200 M	40.0 M	5.0	8.6 k USD
China (internal combustion)		6%	82.4 M	8.00 M	10.3	
India	1.31 B	12%	155.0 M	20.2 M	7.6	2.0 k USD
Indonesia	261 M	29%	76.4 M	5.57 M	13.7	3.9 k USD
Vietnam	94 M	51%	47.7 M	3.39 M	14.1	2.1 k USD
Thailand	69 M	30%	20.5 M	1.82 M	11.3	6.6 k USD
Taiwan	24 M	58%	13.7 M	860 k	15.9	24.3 k USD
Malaysia	32 M	37%	11.7 M	460 k	25.4	9.8 k USD
Philippine	103 M	5%	5.30 M	1.32 M	4.0	3.0 k USD
Pakistan	210 M	5%	10.8 M	1.63 M	6.6	1.5 k USD
Brazil	210 M	6%	13.1 M	1.43 M	9.2	9.9 k USD
Mexico	129 M	2%	2.99 M	680 k	4.4	9.3 k USD
Nigeria	186 M	-	-	1.35 M	-	2.0 k USD
Japan	130 M	9%	11.2 M	350 k	32.0	38.4 k USD
U.S.	330 M	3%	8.70 M	490 k	17.8	59.8 k USD
France	63 M	5%	3.01 M	250 k	12.0	39.9 k USD
UK	66 M	2%	1.33 M	100 k	13.3	39.8 k USD
Russia	147 M	1%	2.00 M	70 k	28.6	11.0 k USD
Spain	46 M	11%	5.00 M	160 k	31.3	28.4 k USD
Italy	60 M	14%	8.50 M	200 k	42.5	32.0 k USD
Germany	83 M	7%	6.10 M	140 k	43.6	44.8 k USD

B denotes billion, M denotes million, and k denotes thousand.

of annual motorcycle sales in India is more than China, it is not restricted to use internal-combustion motorcycles in India.

2.1.6 Number of Motorcycles in Countries around the World and the Expected Growth

Table 5 shows the number of motorcycles in operation, the penetration, the number of annual motorcycle sales [2], [13], [15], [16] and GDP per capita [17] in countries around the world in 2018.

According to the ratio ((A)/(B) in the table) of the number of motorcycles in operation (A) to the number of annual motorcycle sales (B), countries where the ratio (A)/(B) is less than ten seem to be a growing market. In such countries, GDP per capita is several thousand USD, and the penetration is low. India, Philippine, Pakistan, Brazil, and Mexico can be regarded as the growing markets.

In countries where the penetration is high (more than 30%), e.g., Indonesia, Vietnam, Thailand, and Taiwan, the ratio (A)/(B) is around 10 to 15. These countries can be regarded as mature markets.

In countries where the ratio (A)/(B) exceeds 20, they have already shifted to cars as people's primary vehicle. The durable years of actual motorcycles are around 13 years in Japan. Since the ratio of these countries exceeds the durable years, most of the motorcycle demand of the countries seems to be replacement or for enthusiasts. Developed countries, with high GDP per capita, are in this category. In Malaysia, the penetration of motorcycles is high as other south-east Asian countries. However, GDP per capita in Malaysia is exceeding to 10,000 USD with economic growth, and the tax is low because of an oil-producing country. Thus, people in Malaysia seem to be becoming more to change their motorcycle to a car.

On the other hand, in such high ratio (A)/(B) countries, e.g., Japan, most of the decrease of the number is because the decrease of small motorcycles and mopeds as commuters. The demand of ordinary or premium motorcycles is still solid, and such motor-

cycles remain to have the advantage of the motorcycle against the car, as mentioned before.

Considering the penetration of electric scooters in China as shown in Table 5, electric motorcycles will get popular under the right circumstances. Especially in urban areas, since it is cost-effective to implement charge stations, the demand for electric motorcycles is expected to increase.

2.2 Laws and Regulations about Motorcycles in Countries around the World

2.2.1 Tariff (custom duty) in the South and South-east Asian Countries

South and south-east Asian countries are the main markets of motorcycles. The tariff rate on vehicles in these countries is considerably high, e.g., 125% in India, 80% in Thailand, 67% in Vietnam, 40% in Indonesia, 30% in Philippine and 10% in Malaysia, whereas 0% in Japan, 10% in EU and 2.5% in U.S. (depend on vehicle types) [18].

To buy an import motorcycle in Thailand, the amount of payment includes the price of a motorcycle, the tariff (80% of the price), the excise tax (35–45% depending on vehicle types), the municipal tax (10%) and VAT (7%). The payment is almost three times bigger than the original price, and such imported vehicles are for wealthy people. Inside ASEAN countries, the tariff is not applied from 2018, but only less than 300 cc motorcycles are produced in these countries currently. This is a reason why large-sized motorcycles are not popular in those countries. In the near future, large-size motorcycles will be produced locally and will be getting popular in such countries.

2.2.2 Transport Policies by Governments

The Netherlands is known as the country of bicycles, and people use bicycles well in their daily life. It is because not only the land is flat, but also the transport policies provide benefits to bicycle users. The Netherlands, comparing with Asian countries, are wealthy, and its GDP per capita is 48,000 USD (2017, the 13th

highest in the world). The weather is cold, and people afford to buy a car, but most of them choose a bicycle as their primary vehicle. The bicycle roads are well implemented, and bicycle traffic is prioritized over car traffic by the traffic policy. In European countries, parking spaces for bicycles and motorcycles are well implemented comparing with Japan.

Transport policies affects the number of sales of types of vehicles. As mentioned before, the rise of electric motorcycles has also been affected by the transport policy in China.

2.2.3 Regulations for Safety and Environment

In order to achieve traffic safety, each motorcycle has to equip with an anti-brake lock system (ABS) by a regulation [19]. The ABS regulation for more than 125 cc motorcycles becomes effective in the EU from 2017, in India from 2018, in Taiwan from 2019, and in Japan from 2021. For less than 125 cc motorcycles, ABS or a combined brake system (CBS) is required. The regulations contribute the safety, but it makes the development and production cost higher, and it is severe, especially for low-priced motorcycles.

Also, the emission regulation and noise regulation are getting stricter step by step in order to keep good living conditions [20], [21]. These regulations also make the development and production cost higher. Such regulations are globalized nowadays.

The emission regulation EURO4 requires each new motorcycle equip an on-board diagnosis system (OBD) to detect emission sensors' disconnection (called Stage 1). In 2020, EURO5 will become effective, and new sensing systems and faster communication on a control area network (CAN) are required for more precise emission control.

Due to such regulations, a motorcycle has to equip a powerful electronic control unit (ECU) and inside/outside communication networks. Such equipment imposes costs to a motorcycle, but they have the potential to be utilized to obtain additional novel values with information systems and services.

3. Current Situation of Motorcycle Researches and Developments

3.1 Survey of Motorcycle Researches

To survey all motorcycle-related researches, we use the following three digital libraries and search engines:

- SAE (Society of Automotive Engineers) MOBILUS [22]
- CiNii by NII (National Institute of Informatics, Japan) [23]
- IEEE (Institute of Electrical and Electronics Engineer) eXplorer [24]

SAE is the largest society of automotive engineers. JSAE (SAE of Japan) is related to SAE. Most of the published mechanical researches and automotive researches should be listed in SAE MOBILUS.

CiNii lists all articles that are in the National Diet Library in Japan. It also lists the information from Crossref [25], an official Digital Object Identifier (DOI) Registration Agency of the International DOI Foundation.

IEEE is the largest society of electronics engineering, including computer science and informatics. Most of the related researches about Intelligent Transport Systems (ITS) should be

listed in IEEE eXplorer.

3.1.1 Survey on SAE MOBILUS

SAE MOBILUS has archived 154780 articles and documents about automotive engineering and related subjects (as of 2019-10-22). As the search result with the query `motorcycle OR motorbike` in Metadata (abstract, title, and keywords), there are 2239 articles. After eliminating non-technical documents, we have obtained the information of 2119 journal and conference papers of them.

Here, we show the details. The following categorization was conducted by SAE MOBILUS. “(value)” denotes the number of articles and documents. First, the top 3 topics are as follows:

- Simulation and modeling (192)
- Computer simulation (79)
- Mathematical models (64)

The top 3 publishers are as follows:

- SAE (Society of Automotive Engineers) (1157)
- JSAE (Society of Automotive Engineers of Japan) (552)
- NHTSA (National Highway Traffic Safety Administration) (115)

The top 6 affiliations are as follows, and all of them are Japanese institutes and motorcycle manufacturers.

- Honda R&D Co., Ltd. (111)
- Yamaha Motor Co., Ltd. (60)
- Kawasaki Heavy Industries, Ltd. (43)
- Japan Automobile Research Institute (31)
- Suzuki Motor Corp. (24)
- Nihon Univ. (19)

Top 4 events are as follows:

- Small Engine Technology Conference & Exposition (SETC) (413)
- International Technical Conference on Enhanced Safety of Vehicles (ESV) (103)
- JSAE Spring Conference (97)
- JSAE Autumn Conference (75)

SETC and the two JSAE conferences are organized by JSAE, and the other is organized by NHTSA.

According to the above results, most of the motorcycle researches target motorcycle dynamics, its modeling methods, its simulation, and its analysis. Additionally, most of the researches are conducted in Japan, and Japanese motorcycle manufactures.

3.1.2 Survey on CiNii

To investigate more related work to motorcycles, we have checked researches in Japan with CiNii. The search query is `オートバイ OR 二輪車 OR バイク OR motorcycle OR two-wheel`, which includes motorcycle and two-wheel vehicles in Japanese words. As the search result in metadata, there are 3473 articles (as of 2019-10-22). We have checked the metadata of all the articles and eliminated non-related documents and not-technical documents. Finally, we have obtained 977 related articles and documents. Note that since the categorization and elimination have been conducted by the author manually, the list may contain some errors.

First, we have categorized the articles depending on the type of target vehicle as follows:

- Motorcycles (777)

- Two-wheeled vehicles like Segway, and two-wheeled robots (144)
- Bicycles (56)

Hereafter, we focus on the 777 related articles to motorcycles. The major topic is the vehicle dynamics. There are 288 articles related to motorcycle dynamics, and there are 57 articles related to rider's dynamics. The detail of the articles related to motorcycle dynamics are as follows:

- Modeling of motorcycle dynamics (54)
- Sensing of motorcycle dynamics (16)
- Analysis of motorcycle dynamics (123)
- Control of motorcycle dynamics (96)

There are 107 articles focusing on riders, which are not only related to dynamics.

- Modeling of a rider's dynamics (35)
- Sensing of a rider's motion (12)
- About a rider's feeling (15)
- Analysis of a rider's motion and behavior (32)

The detail of the other related articles are as follows:

- Simulation modeling/design of vehicle dynamics, analysis of simulation results (58)
- Analysis of motorcycle traffic for road safety (29)
- Rider's aid system for road safety (24)

There are 93 articles related to information science and computer engineering from the 777 articles. Most of them are published or reported at Japanese major three electrotechnical academic societies, Information Processing Society of Japan (IPSJ), the Institute of Electronics, Information and Communication Engineers (IEICE) and the Institute of Electrical Engineers of Japan (IEEJ). The detail of the 93 articles are as follows:

- Sensing of motorcycle body (11)
- Sensing of rider (4)
- Analysis of rider's feeling and cognition (15)
- User interface system to output information (22)
- Estimation of the road or the surrounding environment from sensed data (8)

Most of the motorcycle researches with information science and computer engineering mainly focus on applications and services for riders or traffic management. With the developments in information and communication technology, it becomes easier to get sensing data of a vehicle body and a rider, to store large data and to analyze the data. The systems and the data may be able to contribute to researches about motorcycle dynamics too in the future.

Other researches related to motorcycles includes the following topics:

- Analysis of riders' injuries (29)
- Analysis of health impact on motorcycle riders (39)
- Analysis of traffic accidents with motorcycles (33)

3.1.3 Survey on IEEE eXplorer

Lastly, we have check motorcycle researches on IEEE eXplorer. Researches with information science and computer engineering can be listed in this digital library. Most of ITS researchers so far are listed there.

The search query is `motorcycle`. There are 1563 articles as the search result in the metadata, and there are 401 articles as the

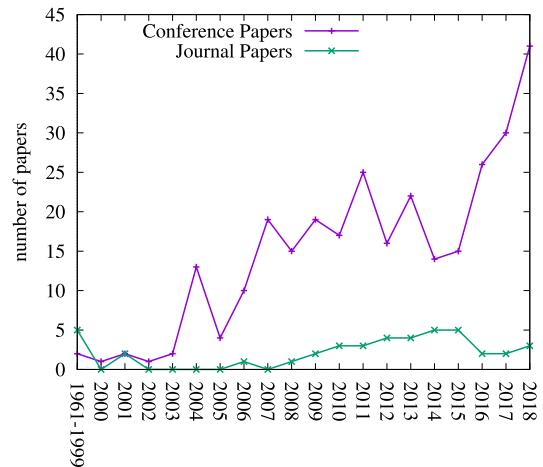


Fig. 2 The number of related papers to motorcycles in IEEE journals and conference proceedings.

search result in the title (as of 2019-10-22). After chosen technical papers from the result in the title, we found 50 journal papers and 305 conference papers related to motorcycles.

Figure 2 shows the number of related papers to motorcycles in IEEE journals and conference proceedings. The number of publications is growth after 2004. Most of them are in the mechanics and electronics area, and there are few researches with ICT. The detail of research topics is similar to the results of CiNii, as shown in Section 3.1.2.

3.2 Challenges of Motorcycle Researches

3.2.1 Lack of Presence of Motorcycles in Future Vision

The European Commission published an Action plan for the deployment of ITS in Europe in 2009 [26] and its original picture, shown in **Fig. 3**, illustrates cars, buses, trucks, trains, ships, and planes but no motorcycles. Motorcycles barely have been added to the picture in 2014. However, in the same year, the Comité Européen de Normalisation (CEN) and the European Telecommunications Standards Institute (ETSI) have published the basic set of standards for Cooperative Intelligence Transport Systems (C-ITS) as a Européen de Normalisation (EN) document without respect to motorcycles.

For example, the Cooperative Awareness Message (CAM) and the Decentralized Environmental Notification Message (DENM) specified in ESTI EN 302 637-2/3 and ESTI TS 102 894-2 are not designed to consider the difference of the running position between a motorcycle and a car. When a motorcycle is passing though among congested cars, a traffic system on the standards may be confused. According to the standards, the message has data fields about parking brake, door opening, and trunk opening. A motorcycle does not have such functions, but the system for a motorcycle will have to pad the data fields with something useless. Also, the specified steering wheel angle is at a 1.5-degree resolution, and its range is ± 720 degrees in the message. However, the actual steering angle of a motorcycle is generally ± 3 degrees, and the resolution is too coarse.

There are many such messages in the standards. However, once the standards are established, a new product has to conform to the standards, and it needs much effort to revise because the durable



Fig. 3 The picture of ITS vision in Europe by ESTI (2009) [26].

years of automotive products are much longer than IT devices. Additionally, the interoperability of automotive products is also essential more than IT devices because it is easy to involve human lives. To design an IT system for a motorcycle, we need to be more careful about safety.

3.2.2 Intractability of Motorcycle Sensing and Rider Sensing

The weight ratio of a rider to the body of a motorcycle is much larger, comparing with other vehicles, e.g., a car, a ship, and a plane. A rider moves their body and their center of gravity to maneuver the motorcycle they ride. A rider's movement affects the dynamics of the system consists of both a motorcycle body and the rider. Thus, when considering the motorcycle dynamics, we need to consider a rider's body, a motorcycle's body, the ride's motion, and the motion of a motorcycle together.

To investigate the motorcycle dynamics analytically, we need many data to confirm the hypotheses. In the current researches, mechanical researchers and engineers have worked on motorcycle dynamics, analyzing a mathematical model of vehicle motion and investigating it with measured data empirically. However, it is difficult to confirm the soundness of the model in the former, and it is costly and sometimes impossible to measure a vehicle and a rider's motion accurately in the latter so far.

In order to measure the motorcycle dynamics, it is impossible to share methods for four-wheel vehicles because the motion of a motorcycle is much different from that of a car. Dedicated methods and researches are needed to investigate the motorcycle dynamics. The motion of a plane is partially similar to that of a motorcycle, for example, the rolling motion. However, other parts are much different. To measure not only the motion of a motorcycle body but also that of a rider, we need more researches and developments. In order to measure the human body's motion and activity, there are many related work [27], but it is still hard to obtain accurate sensing data because of calibration issues, etc.

3.3 Connected Motorcycles

The connected-car services will be realized in the near future. After that, all vehicles connect with each other via the Internet, and they share their probe data for generating traffic information and achieving traffic safety. Such data can be used for novel

ADAS and ITS services.

Currently, it is not easy for a motorcycle to obtain the same benefit as for cars, as discussed above. If motorcycles will also connect to them, and motorcycle riders will obtain a benefit for such ITS services, the whole transportation system may become smarter and more efficient. Probe data from motorcycles have unique characteristics because of their dynamics. The data can complement that from other vehicles, and it may contribute to constructing a smart city.

3.3.1 Detail of Motorcycle Accidents in the Developed Countries [28]

In a traffic accident including a motorcycle, the other party is a car in 60 to 90 percent of the cases. In 50 to 70 percent of such a case, the car is the party with primary responsibility for the accident. A 15 to 30 percent of motorcycle accidents occur at an intersection. The main cause of 94 percent of such accidents is the responsible driver or rider. Seventy-four percent of the fault of the driver or rider is a cognitive error and an error in judgment. Other causes of a few percents are defects of the vehicle and the road infrastructure.

A motorcycle is likely to be involved in a traffic accident with a car. It is because the driver underestimates the distance to a motorcycle as farther or the motorcycle often vanish from the driver's sight. In order to reduce traffic accidents with a motorcycle, it is required to make the visibility of a motorcycle higher or to develop a mechanism that lets a car driver notice a motorcycle well.

3.3.2 CMC: Connected Motorcycle Consortium [29]

With the progress of ADAS and ITS, the number of total deaths from traffic accidents has been drastically reduced in these two decades in Japan. The number in 2018 is less than a half against 20 years ago in Japan. On the other hand, the number of motorcycle riders' deaths has reduced a little, whereas the number of motorcycle riders is decreasing in the developed countries: Japan, U.S., and European countries. Thus, the traffic safeness of motorcycles has not been improved. Therefore, in order to reduce the number of motorcycle riders' deaths, the Connected Motorcycle Consortium (CMC) has been founded by Honda, Yamaha, and BMW in 2016. Currently, other manufacturers, including Suzuki, Kawasaki, and KTM, research institutes in Europe and motorcycle-parts vendors have joined so far.

3.3.3 Cooperative Integrated Transportation Systems (C-ITS) [30]

C-ITS are expected to provide various services for connected vehicles to achieve smart, safe, and efficient traffic systems. The purpose of CMC is to have motorcycles and motorcycle riders contribute to and receive benefits from C-ITS.

As mentioned above, to reduce motorcycle accidents with cars, it is essential to prevent a car driver's cognitive error to a motorcycle. At a motorcycle accident with a car, 90 percent of the car driver did not notice the motorcycle, and remaining 7 percent of them were not able to do anything to avoid the accident after noticed the motorcycle.

In order to reduce such an accident, it is essential to notice the information to the driver or to control the car before the collision. As the preventive safety, the notification should be provided more than 2 seconds before the time to collide (TTC).

3.4 Designing of an Accident Avoidance System for Motorcycles

To realize the safety for motorcycles, coming ADAS for a motorcycle rider needs the following considerations. A rider can aware and recognize obstacles and traffic environments only on their sight. As inputs of the system, it should not only depend on a rider's eyes but also get the information from C-ITS. Then, the system should control a vehicle or output the information to the rider. Here, we summarize the considerations as follows:

Inputs

- awareness and recognition by a rider's eyes
- both visible and invisible information about surroundings by C-ITS

Mechanisms

- a rider and passengers
- a motorcycle
- C-ITS

Control

- a rider's skills and cognitive functions
- a motorcycle motion and performance

Outputs

- messages to a rider and passengers
- messages to control a motorcycle
- messages to C-ITS

3.4.1 Sensing and Positioning of a Motorcycle as the Input Data

As inputs of the system, it is essential to measure the current situation with sensors. The position, the attitude, and the speed of a motorcycle can be used as inputs.

The position is usually obtained with a GNSS receiver. In order to let a GNSS receiver derive accurate positioning information, it is required to put the GNSS antenna on a place where no surrounding obstacles are blocking the direct signal from each GNSS satellite. However, there is little space for the antenna on a motorcycle, whereas a car has such space enough. A rider, a passenger, equipment of a motorcycle body, and pannier cases can be obstacles blocking the signals. Although the target frequency of a signal is different, Ref. [31] reports that a motorcycle passenger degrades a signal strength by 20 dB. The attitude of a motorcycle can widely change, and the attitude of an equipped antenna on the motorcycle is also widely changed. It affects the received signal quality. Currently, there are a few related works about an on-board antenna on a motorcycle [31]. We need to specify the requirements of target applications for a motorcycle as follows: where is an appropriate place to equip such antenna and what quality of the antenna is needed.

An inertial navigation system (INS), which consists of an inertial measurement unit (IMU) and a GNSS receiver, is usually used to obtain the attitude of a vehicle. In order to develop an INS for a motorcycle, more development and validation are needed. We need to specify its requirements considering target applications for a motorcycle.

3.4.2 Information Presentation as the Output to a Rider

The instrumental panel of a car and a car navigation system have a large LCD monitor and speaker. A car driver can obtain information through the display and the speaker. On the other hand,

the meter of a motorcycle is small, and the speaker equipped on a motorcycle may not work well because the wind roar disturbs the audio communication, e.g., 100 km/h winds make 100 dB noise. Several head-up-displays (HUD) built in a helmet have been proposed but have not become a product yet [32]. It is not easy to communicate information to a motorcycle rider while riding.

For information presentation for a car driver, Japan Automobile Manufacturers Association, Inc. (JAMA) shows guidelines to design a system. Guidelines for In-vehicle Display Systems—Version 3.0 by JAMA [33] shows the requirements such as “a display system is so designed that its adverse effect on safe driving will be kept to a minimum.” However, there are no such guidelines for display systems for a motorcycle rider so far.

3.4.3 Instrument Panel of a Motorcycle as an Information Display

Most of the latest flagship sport-type motorcycles and luxurious motorcycles for leisure have a large LCD information display like a smartphone. Such a display can connect with smartphones via wireless communication, e.g., Bluetooth, and can show navigation information too. Obtained information via C-ITS can also be displayed there.

On the other hand, the most common type of motorcycles in the main markets is a 100 to 150 cc motorcycle, and it has just conventional simple speed meter. It is hard to show C-ITS information on such a meter.

It is also essential to discuss how to indicate information safely and effectively to a motorcycle rider, whether it has a large display or not.

3.4.4 Smartphone as a User Interface to a Motorcycle

Since most of the motorcycles do not have a display to show C-ITS information, a rider's smartphone can be a candidate as the display. **Table 6** shows the penetration of smartphones [34] and Internet [35] in countries around the world. In Asian countries, as the main market, the penetration is so high.

A rider's smartphone may be used as the display, but we need to discuss how to equip the smartphone on a motorcycle appropriately.

Table 6 Penetration of Smartphone [34] and Internet [35].

(a) Asian countries		
country	smartphone	Internet
China	83%	56.7%
Taiwan	81%	87.9%
Thailand	71%	82.4%
Malaysia	88%	78.3%
Singapore	91%	83.6%
Indonesia	60%	53.7%
Vietnam	72%	66.3%
Philippine	65%	62.9%
India	40%	34.1%
(b) Developed countries		
country	smartphone	Internet
Japan	64%	93.3%
Korea	92%	92.6%
U.S.	78%	87.9%
Canada	76%	90.1%
UK	77%	94.8%
France	71%	86.8%
Germany	75%	89.6%
Italy	76%	86.7%
Spain	87%	87.1%

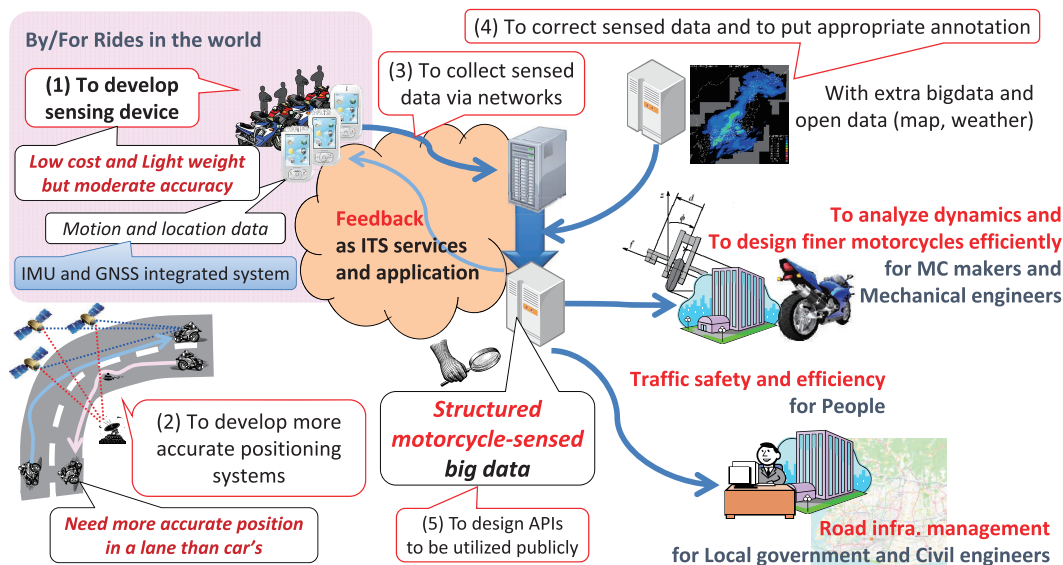


Fig. 4 System Chart of Bikeinformatics.

4. Introduction of Bikeinformatics: The Concept Using Informatics to Research Motorcycles

The purpose of Bikeinformatics (BKI) [36] is to put a motion and location-sensing device to all motorcycles in the world and to build bigdata of the riders, by the riders, not only for the riders as shown in Fig. 4. One of the motivations is to collect such data from a lot of motorcycles and riders in order to help mechanical engineers analyze motorcycle dynamics and to also help motorcycle manufacturers design more sophisticated motorcycles efficiently. Another is to use such data to help riders enjoy riding safely and conveniently. The other is to utilize such data socially. For example, it can be used to achieve traffic safety and efficiency for other people, and to manage road infrastructure for local government and civil engineers. Moreover, it can be used to improve traffic safety in mixed traffic with motorcycles and automated cars.

There are mainly five challenges:

- (1) How to develop low-cost and light-weight but moderate accuracy sensing device for a motorcycle.
- (2) Due to the high mobility of a motorcycle, it needs more accurate positioning system to utilize such mobility.
- (3) How to collect sensed data via communication networks and how to store all sensing data around a motorcycle: a motorcycle's motion and a rider's motion by IMUs, trajectory by a GNSS receiver, and image and video by cameras.
- (4) How to correct sensed data and to put appropriate annotation with external bigdata and open data, such as digital map and weather information, because it is possible to associate weather information with motion sensing data by using time and location information of the sensed data.
- (5) How to design application programming interfaces (APIs) to be utilized publicly.

In this paper, we introduce the progress of the early phases of the concept.

4.1 Precise Positioning and Timing for Motorcycle Sensing Data

Positioning data and timing data are mandatory for ITS services and applications. In this decade, Galileo by EU and BeiDou by China have become available for people as available GNSS, in addition to GPS by U.S. and GLONASS by Russia. Japan and India also have launched and have operated their regional navigation satellite systems (RNSS), QZSS, and NavIC, respectively. The availability and accuracy of such multi-GNSS have become better. Moreover, precise positioning with GNSS, e.g., real-time-kinematic GNSS (RTK-GNSS), becomes realistic for consumers' services because of increased the number of available navigation satellites and decreased the price of GNSS receivers for precise positioning.

RTK-GNSS allows us to obtain centimeter-level accurate positioning results reasonably in the current situation, whereas the accuracy of the conventional positioning method with GNSS is within several meters. Until several years ago, it was difficult to stably obtain such precious position information with RTK-GNSS due to the lack of available navigation satellites. The success rate of precise positioning depends on the situation, but the rate was usually less than 10% on the road. At that time, the error of a positioning result became more than several meters. Now, the success rate of precise positioning with RTK-GNSS becomes more than 50%, and it is reasonable for some services and applications.

The availability and stability of the accuracy of positioning results are required to use such precise positioning for ADAS and critical ITS services. Even for non-critical ITS services, more accurate positioning information is required for motorcycles. For example, a motorcycle can run freely within a road, whereas a car usually runs through along the center of a road because of the vehicle width (*). The precise trajectory of a motorcycle should be measured to utilize its mobility. This difference in mobility affects the sensing performance between a probe motorcycle and a probe car.

Table 7 Measurement system of precious positioning experiment.

On-board logger	
GNSS module	u-blox NEO-M8T + Tallysman TW2710
Measurement rate	5 Hz
Reference Station on Hamamatsu Campus, Shizuoka University	
GNSS module	Trimble NetR9 + Zephyr Geodetic 2 RoHS
Experiment Field	150 meters' straight road near the campus
Baseline length	< 1 km
Measurement rate	1 Hz
GNSS systems	
Positioning Software	RTKLIB 2.4.3 b33 [37]
App/Mode/Filter	PTKPOST / Kinematic / combined



Fig. 5 Road for the positioning experiment.

Table 8 Experiment setting and positioning result.

	Car	Motorcycle
vehicle	660 cc Kei-car	50 cc mini-scooter
speed	around 40 km/h	around 30 km/h
# of trials	30	30
# of FIX solutions (accuracy < 10 cm)	2299 epochs of 2381	612 epochs of 2258
σ of longitudinal direction of all FIX solutions	0.16 meters	0.51 meters

To ensure the above claim (*), we have conducted the following experiment. We have obtained the precise trajectory of a car and a motorcycle, and we have confirmed that the difference in the width of running ranges between the car and the motorcycles. **Table 7** shows the measurement device with RTK-GNSS and **Fig. 5** shows the road in a residential zone the experiment conducted. **Table 8** shows the experiment settings and the statistical results. **Figure 6** and **Fig. 7** show the trajectories of the car and the motorcycle, respectively. In these figures, FIX solutions (green points) indicate positioning results with a few centimeters' accuracy, and FLOAT solutions (orange points) indicate positioning results with a few meters accuracy. FIX solutions are obtained only when the measurement condition of the antenna and the receiver is appropriate. As shown in Fig. 6, even FLOAT solutions look accurate because a car has the roof, and it is an appropriate place to equip the GNSS antenna. On the other hand, as shown in Fig. 7, FLOAT solutions do not look accurate because the GNSS was equipped on the rear deck of the motorcycle and the rider's body often blocked the direct signal from GNSS satellites.

Focusing on only FIX solutions and fitting the solutions as Gaussian distribution, we have derived the variance, σ , and the two-sided 95% confidence interval of their running longitudinal position, $\pm 2\sigma$, as shown in **Fig. 8**. The 95% confidence interval of the motorcycle is 2.04 meters, whereas that of the car is 0.64 meters. With RTK-GNSS, we have confirmed that a motorcycle

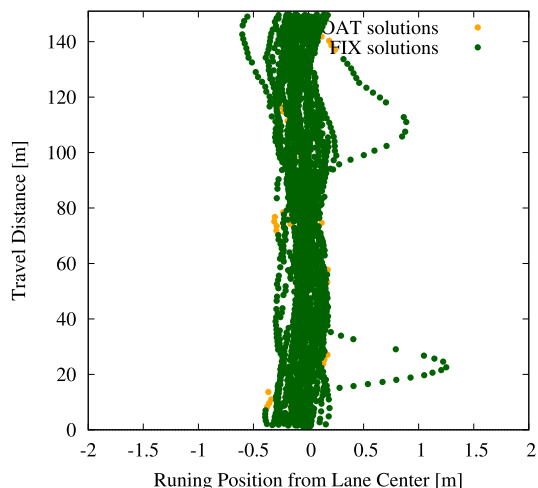


Fig. 6 Trajectories of the car in the lane.

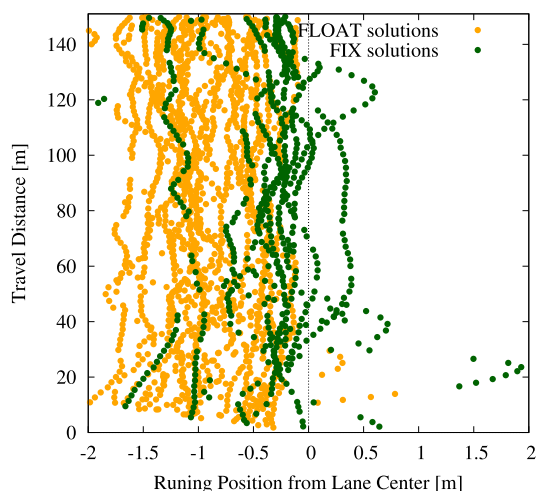


Fig. 7 Trajectories of the motorcycle in the lane.

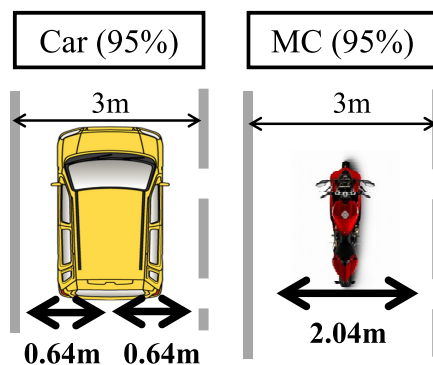


Fig. 8 $\pm 2\sigma$ area of each vehicle as the sensing range of road surface.

can run more widely on the road than a car.

4.2 Measurement of the Motion of a Motorcycle Body

The committee of the motorcycle division of JSAE and engineers in manufacturers have been discussing sensing systems for measuring motorcycle dynamics. **Table 9** shows the measurement items that have to be measured in order to analyze the vehicle motion of motorcycles. The items with "Required for analyzing motorcycle dynamics" in the table should be measured according to Refs. [38], [39]. JSAE Motorcycle WG has conducted several experiments, and they use the sensing systems that

Table 9 Measurement items to investigate motorcycle dynamics [38].

Required for analyzing motorcycle dynamics			
		by JSAE Motorcycle WG	
			by proposed system
Speed	✓	✓	✓(GNSS)
Roll Rate	✓	✓	✓(IMU)
Roll Angle	✓	✓	calculable
Yaw Rate	✓	✓	✓(IMU)
Yaw Angles	✓	✓	calculable
Acceleration	✓	✓	✓(IMU)
Steering Angle	✓	✓	*
Steering Torque	✓	✓	*
Slip-side Angle	✓	✓	*
Trajectory		✓	✓(GNSS)
Cost	-	high	low
Weight	-	high	low

* It may be measured with IMU and GNSS, but it needs an estimation model.

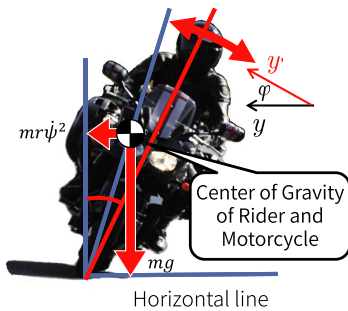


Fig. 9 Dynamic roll angle and body roll angle of a motorcycle.

measure all the items in the table, but it is expensive and heavy. Actual running experiments have been conducted several times by the committee [40].

In Bikeinformatics, we target to develop a low-cost, small-sized sensing system that measures some of the fundamental measurement items. We have proposed a sensing system with a few inertial measurement units (IMU), which includes a 3-axis accelerometer and a 3-axis gyroscope sensor, and a GNSS receiver to measure the items in Refs. [36], [41].

4.3 Measurement of the Motion of a Rider

There are two roll angles: the dynamic-roll angle and the body-roll angle, as shown in Fig. 9. The dynamic roll angle is the angle between the horizontal line and the line connecting the combined center of gravity of a motorcycle and its rider and the contact point between the tire and the ground. The combined gravity center fluctuates depending on the rider's motion.

The dynamic roll angle can be estimated by the centrifugal force and the height of the combined center of gravity of a motorcycle and its rider when the motorcycle is balanced. The centrifugal force can be calculated by the yaw-rate and speed from GNSS receivers. However, it does not work while a motorcycle is losing a balance. Also, it is difficult to estimate the height of the combined center of gravity.

It is not easy to directly obtain a rider's position and attitude so far. With RTK-GNSS, it can obtain a rider's position and attitude directly.

We have conducted an experiment to measure a rider's position and attitude directory. We put each RTK-GNSS receiver on a rider's helmet and the directional axis of the motorcycle, as shown

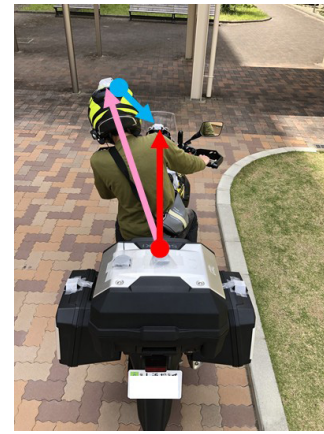


Fig. 10 Riding position measurement with RTK-GNSS.

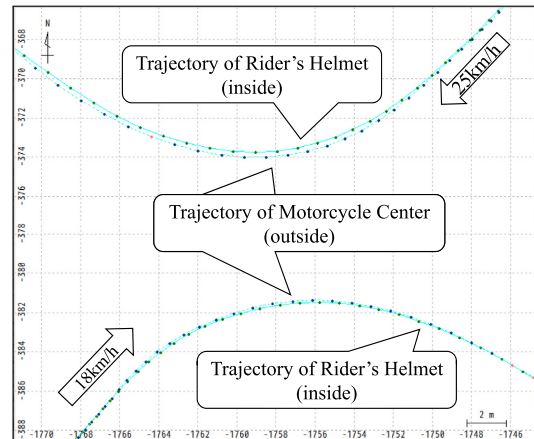


Fig. 11 Precise trajectories of motorcycle center and rider's helmet.

in Fig. 10. The detail of GNSS receivers is as shown in Table 7.

Figure 11 shows the precise trajectories of both receivers on the helmet and the motorcycle. The difference between those two trajectories shows how much the rider moves their body.

Due to the centimeter-level accuracy of RTK-GNSS, we have confirmed that a part of a rider's motion can be measured directly and reasonably. Although the sampling rate of a GNSS receiver is not high (up to 10 Hz), sensor fusion with an IMU with a higher sampling rate will work well.

5. Conclusions

We have explained the current situation of the motorcycle industry and motorcycle researches and developments. Motorcycles and coming evolved motorcycles have much potential to make future transportation better. We have introduced the concept of Bikeinformatics, a bigdata by motorcycles and riders, and how informatics and its related science and engineering can contribute the motorcycle researches.

To utilize such high mobility of the motorcycles and personal vehicles, the conventional positioning accuracy (within several meters) is not enough. In this paper, we have introduced precise positioning information (within a few centimeters) and its usage as a label for measured motorcycle data. It is essential to build a bigdata with meaningful labels. The quality of bigdata does not only depend on the resolution of measured data but also depends on the resolution of its label. Such accurate position information

lets us improve the accuracy of measured data by aggregating the data. Accurate labels let even so small amounts of data have sufficient meanings.

As future work, we will work on the remaining issues of Bike-informatics: how to gather sensed data from motorcycles to build a motorcycle bigdata and how to utilize the bigdata.

We hope that this paper help other researchers to start new motorcycle research.

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