Smart Helmet in Applied Sciences

Subjects: Instruments & Instrumentation
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A smart helmet is a wearable device that has attracted attention in various fields, especially in applied sciences,

Keywords: wearable device ; smart helmet ; sensor ; microcontroller ; wireless communication technology

1. Introduction

A wearable (electronic) device is a smart electronic device that can be planted on the body or worn with accessories. Since Google recently launched its head-mounted display, wearable devices have garnered a significant amount of attention [1]. Wearable devices have been able to take an important position in the home appliance market in a short period and are considered a new means of meeting the requirements of many industries. For example, the construction industry has studied the use of wearable devices in the workplace for health and safety management by close detection and physiological monitoring of construction workers [2]. The logistics industry has begun using wearable barcode scanner gloves to simplify work that does not involve hand use [3]. Some insurance companies encourage healthy eating habits and use wearable devices to improve the health of corporate workers [4].

There are different types of smart wearable devices, such as helmets, watches, glasses, contact lenses, textiles, fabrics, headbands, beanies, caps, rings, bracelets, and earrings [5]. Among these, this study focused on smart helmets. Smart helmets include multiple electronic devices and sensors that help users gather real-time data and assist them in reducing operational risks and improving safety in the long run. The global smart helmet market size was valued at USD 372.4 million in 2018 and is expected to expand at a compound annual growth rate of 18.6% from 2019 to 2025 [6].

Research on smart helmet applications is being conducted in various fields to improve safety and efficiency of motorcyclists [7] and workers [8][9]. For example, Singh et al. [7] studied the application of smart helmets to detect portholes and collect air quality data on roads. Wang et al. [8] detected stair fall by analyzing changes in weight support and pressure center using a smart helmet, and Mohammed et al. [9] used smart helmets to prevent the spread of coronavirus by measuring the body temperature and personal information of pedestrians. Like some of the examples mentioned earlier, many studies related to the development and application of smart helmets have been reported in the literature [10][11][12][13][14][15][16][17][18][19][20][21][22][23][24][25][26][27][28][29][30][31][32][33][34][35][36][37][38][39][40][41][42][43][44][45][46][47][48][49][50][51][52][53][54][55][56][57][58][59][60][61][62][63][64][65][66][67][68][69][70][71][72][73][74][75][76][77][78][79][80][81][82][83][84][85][86][87][88][89][90][91][92][93][94][95][96][97][98][99][100][101][102][103][104][105][106][107][108][109]; however, no systematic review has been conducted to analyze the current status and trends of smart helmet research.

The purpose of this study was to review the current status and trends of smart helmet research systematically. The current status of smart helmet research by year and application field were investigated by analyzing 103 academic research articles published in the past 11 years (2009–2020). The types of sensors, microcontrollers, and wireless communication technology were analyzed to identify the trends in smart helmet studies.

2. Current Status of Publications Related to Smart Helmet Research by Year and Source

The number of publications on smart helmets during the past 11 years is shown in Figure 2. In the first seven years (2009–2015), there were limited articles, with an average of 1.28 articles per year. In the next two years (2016 and 2017), the average number of publications increased to 8.5. In 2018, the number of publications more than doubled from the previous year's average, surging to 21 publications. In 2019, there were 27 publications, and, in 2020, the number of publications was 29, making it the highest number for a year overall. The average number of publications in the last three years (2018–2020) was 25.6, which is nearly three times higher than the average number of publications in 2016 and 2017. Therefore, research on smart helmets has been extremely active recently. Additionally, the sources of publications were academic journals (55.3%) and conference proceedings (44.7%).

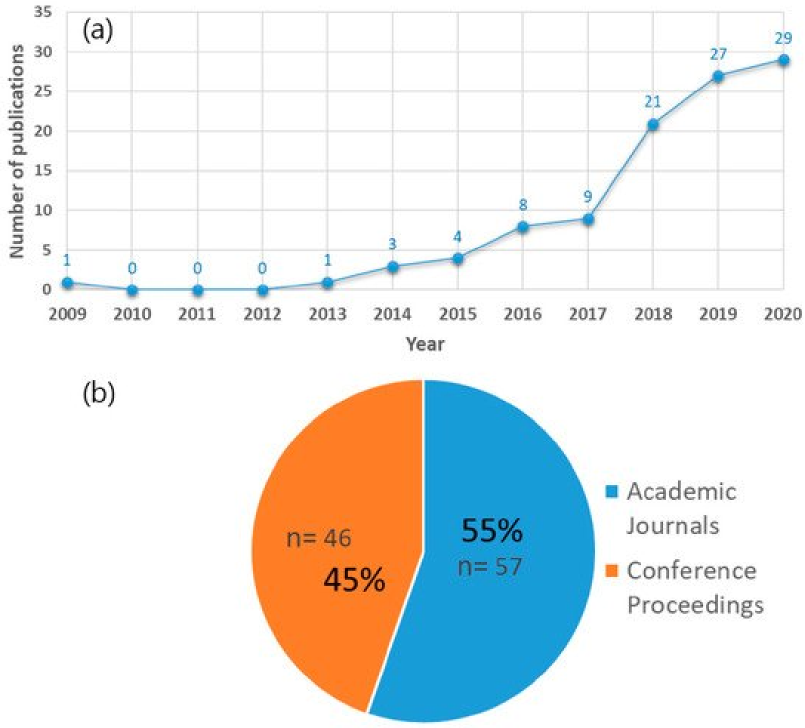

Figure 1. Number of publications related to smart helmet research by (**a**) year and (**b**) source of publications.

3. Application Fields of Smart Helmet Research

The current status of smart helmet studies in each application field was analyzed to determine which fields were studying and utilizing smart helmets the most. The smart helmet applications were organized in two stages to observe the classification at a glance. In the first stage, the studies were classified into two categories (i.e., motorcyclists and workers) according to users of smart helmets. In the second stage, detailed application fields were added below the first stage, as shown in Figure 2. Figure 3 shows the cumulative number of publications on smart helmets during the past 11 years in the first stage of the classification criteria. As shown, studies on smart helmets for motorcyclists and workers have been increasing every year; however, the rate of increase is relatively faster for motorcyclists. This indicates that research on smart helmets for workers must be accelerated.

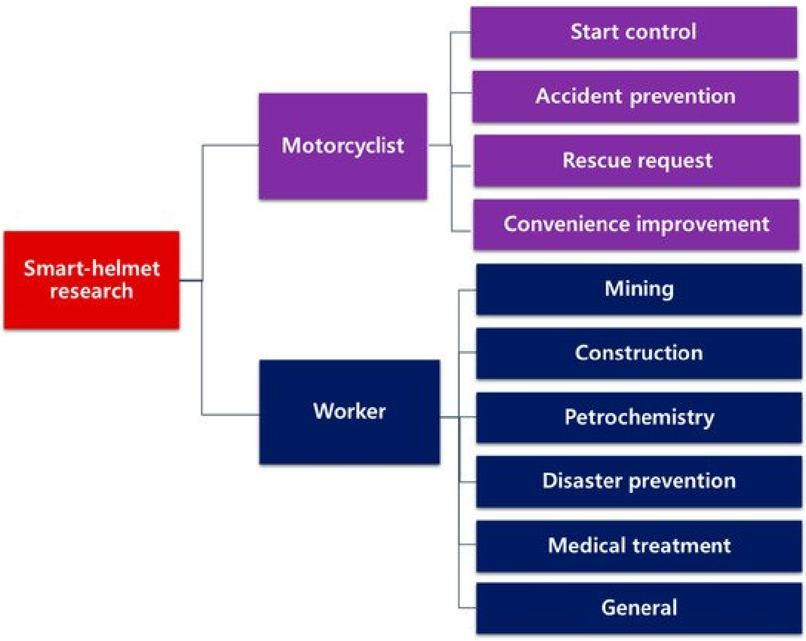

Figure 2. Classification of application fields in smart helmet studies.

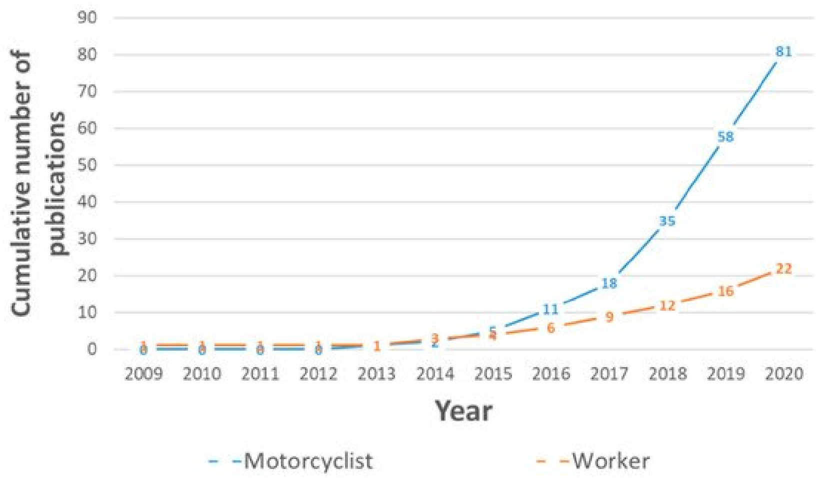

Figure 3. Cumulative number of publications by year in bike, occupational safety, disaster prevention, and medicine fields.

The applications of smart helmets for motorcyclists consist of 81 studies that account for the largest number of publications [7][10][11][12][13][14][15][16][17][18][19][20][21][22][23][24][25][26][27][28][29][30][31][32][33][34][35][36][37][38][39][40][41][42][43][44][45][46][47][48][49][50][51][52][53][54][55][56][57][58][59][60][61][62][63][64][65][66][67][68][69][70][71][72][73][74][75][76][77][78][79][80]. These applications can be classified into four subcategories: start control, accident prevention, rescue request, and convenience improvement. Some studies fall under more than one subcategory when the developed smart helmet is used for various purposes by motorcyclists. Figure 4 shows the percentage of studies according to the subcategory. Note that most smart helmets for motorcyclists have been developed for the start control of motorcycles (42.3%) and rescue requests in the case of an accident (39.2%).

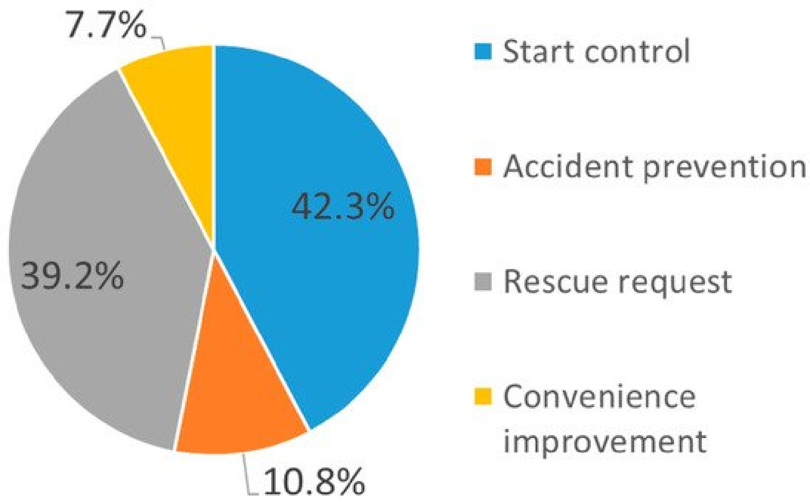

Figure 4. Percentage of smart helmet studies for motorcyclists by sub-category.

The application fields include mining, construction, petrochemistry, disaster prevention, and medical treatment. Figure 5 shows the percentage of smart helmet studies conducted in each application field.

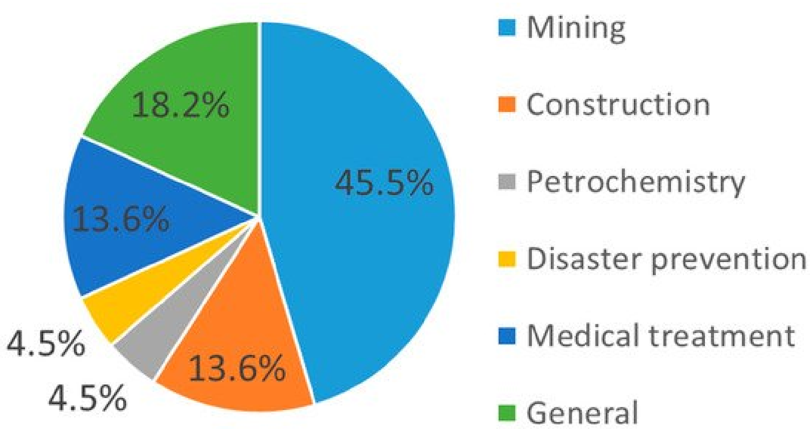

Figure 5. Percentage of smart helmet studies for workers by sub-category.

Table 1. Summary of smart helmet applications for workers in the fields of mining, construction, petrochemistry, disaster prevention, medical treatment, etc.

Reference	Year	Feature and High-Level Functionality	Application (Sub-Category)	Sensor	Microcontroller	Wireless Technology
Wang et al. [8]	2020	Detects stair fall by analyzing changes in weight support and pressure center	Construction	Accident detection	Single board MCU (Arduino)	Bluetooth
Mohammed et al. [9]	2020	Helps prevent the spread of coronavirus by measuring the body temperature and personal information of pedestrians	Medical treatment	Temperature detection	Single board MCU (Arduino)	Bluetooth
Qiang et al. [90]	2009	Real-time monitoring of methane, temperature and humidity data and support for voice communication between operators	Mining	Harmful gas detection; Humidity detection; Temperature detection	Chip MCU (S3C44BOX)	ZigBee
Shabina [91]	2014	Transmits real-time temperature, humidity, and fire data through a wireless network and alerts the operator by sounding an alarm when the threshold is reached	Mining	Temperature detection; Humidity detection; Fire detection	Chip MCU (AT89S52)	N/A
Behr et al. [92]	2016	Collects data on the concentration of harmful gases, whether the helmet is worn, and the amount of impact on the helmet, and transmits and analyzes it to the cloud server	Mining	Harmful gas detection; Helmet wear detection	Chip MCU (ATZB-24-A2)	ZigBee
Hazarika [93]	2017	Measures the concentration of harmful gas and sends it to the cloud server for real-time monitoring and alarms in the control room when the threshold is exceeded	Mining	Harmful gas detection	Single board MCU (Arduino)	ZigBee
Sharma and Maity [94]	2018	Measures the concentration of harmful gases, temperature, and humidity, sends them to the cloud server for real-time monitoring, and sounds an alarm when the threshold is exceeded	Mining	Harmful gas detection; Temperature detection; Humidity detection	Single board MCU (Arduino)	ZigBee
Revindran et al. [95]	2018	A wireless sensor network was built and rescue request was from nearby workers and medical teams when workers send distress messages	Mining	Accident detection	Chip MCU (Arduino)	RF
Eldemerdash et al. [96]	2019	Temperature and humidity, harmful gas concentration, and pressure data are monitored, and when thresholds are reached, warnings are sent through LEDs and buzzers	Mining	Temperature detection; Humidity detection; Harmful gas detection	Single board computer (Raspberry Pi)	ZigBee

Reference	Year	Feature and High-Level Functionality	Application (Sub-Category)	Sensor	Microcontroller	Wireless Technology
Sanjay et al. [97]	2019	Temperature and humidity, harmful gas concentration, and pressure data are monitored, and when thresholds are reached, warnings are made through LEDs and buzzers	Mining	Temperature detection; Humidity detection; Harmful gas detection	Single board MCU (Arduino)	ZigBee
Charde et al. [98]	2020	Collects harmful gas concentration, humidity, and temperature data to enable real-time monitoring and alerts through buzzer and LCD when hazardous concentrations are reached	Mining	Temperature detection; Humidity detection; Harmful gas detection	Chip MCU (PIC)	ZigBee
Sujitha et al. [99]	2020	Detects temperature and humidity, light intensity, toxic gas levels in the air, traces of flames, etc. and warns when thresholds are exceeded	Mining	Temperature and Humidity detection; Brightness detection; Harmful gas detection; Fire detection	Single board MCU (Arduino)	WiFi
Pirkl et al. [100]	2016	IR camera sensor measures the temperature of the surrounding environment	Construction	Temperature detection	Chip MCU (IntelEdison)	Bluetooth
Lee et al. [101]	2019	Detects falls, air quality, and objects fall and sends data to the cloud server for storage	Construction	Harmful gas detection; Accident detection	Single board MCU (Arduino)	Bluetooth
Li et al. [102]	2014	Inertia and brain waves are measured to analyze injury and fatigue, and vibration alerts when thresholds are exceeded	General	Brainwave detection; Motion detection	Chip MCU (PIC)	N/A
Dhingra et al. [103]	2018	Voice communication between workers is possible and rescue request through panic button in case of crisis	General	Accident detection	Single board MCU (Arduino)	RF
Aston et al. [104]	2020	Impulse quantity is dispersed	General	N/A	Chip MCU	N/A
Campero-Jurado et al. [105]	2020	Temperature and humidity, harmful gas concentration and brightness are detected and transmitted to a cloud server for analysis	General	Temperature and Humidity detection; Brightness detection; Harmful gas detection	Chip MCU (PIC)	WiFi
Shu et al. [106]	2015	Early warning in case of leakage of harmful gas	Petrochemistry	Harmful gas detection	Smart device (Smartwatch)	WiFi
Bisio et al. [107]	2017	Detects stroke in emergency patients	Medical treatment	Brainwave detection	Smart device (Smartphone)	Bluetooth
Shahiduzzaman et al. [108]	2019	Detects a fall, sends medical data to the medical cloud, and requests rescue	Medical treatment	Accident detection	Smart device (Smartphone)	Bluetooth

Reference	Year	Feature and High-Level Functionality	Application (Sub-Category)	Sensor	Microcontroller	Wireless Technology
Jeong et al. [109]	2018	Infrared image, optical image, drone image, oxygen residual amount, inertia, etc. are collected	Disaster prevention	Harmful gas detection	Smart device (Smartwatch)	WiFi

In the mining industry, 10 studies were performed on a smart helmet that detects harmful gases, such as carbon monoxide (CO) and methane (CH_4), and guarantees the safety of workers through rescue requests in the case of a dangerous situation [90][91][92][93][94][95][96][97][98][99]. Three studies have been reported in the construction industry, where smart helmets were primarily used to detect workplace hazards and provide risk alarms to construction workers [8][100][101]. For example, a safety helmet with gravity and head movement sensors was used at the construction site to detect a falling worker and activate emergency rescue requests [8]. Four studies on smart helmets were conducted to support voice communication between workers and warn them by detecting injuries in general manufacturing sites [102][103][104][105]. A smart helmet that ensures the safety of workers by warning the occurrence of harmful gas leaks was developed in the petrochemical industry [106].

Three studies [9][107][108] on smart helmets were found in the medical field to improve the work efficiency of medical staff and ensure the safety of patients. In this application, a smart helmet worn by the medical staff was used to detect body temperature and brain waves in emergency situations [9][107]. A smart helmet was developed for medical staff to detect the body temperature of a pedestrian in real time. It was used to prevent coronavirus by warning them through an alarm when discovering a high-temperature pedestrian. Additionally, a study developed a smart helmet to prevent elderly patients lying in bed from falling [108]. One study reported in the literature dealt with a smart helmet for disaster prevention [109]. In this study, the smart helmet was used to support rescue workers at disaster sites.

4. Sensors Used for Smart Helmet Applications

Various sensors are attached to a smart helmet based on the application field and purpose. Table 2 shows the types of sensors used in smart helmet studies. The sensors can be broadly classified into three types: human health, environment, and machine monitoring. The cumulative number of sensor types used in smart helmet studies by year is illustrated in Figure 6a. The use of sensors to monitor human health is increasing every year. The frequency of use of environmental monitoring sensors has also increased in recent years. The percentages of sensor uses for each sensor type are shown in Figure 6b–d. For human health monitoring, the accident detection sensor accounts for 32%, followed by the helmet wear detection sensor and alcohol detection sensor with 30% and 27%, respectively. In the case of environmental monitoring, sensors for harmful gas detection, video shooting, and temperature detection each account for 23%. For the machine monitoring, the speed detection sensor occupies 70% and is the most used.

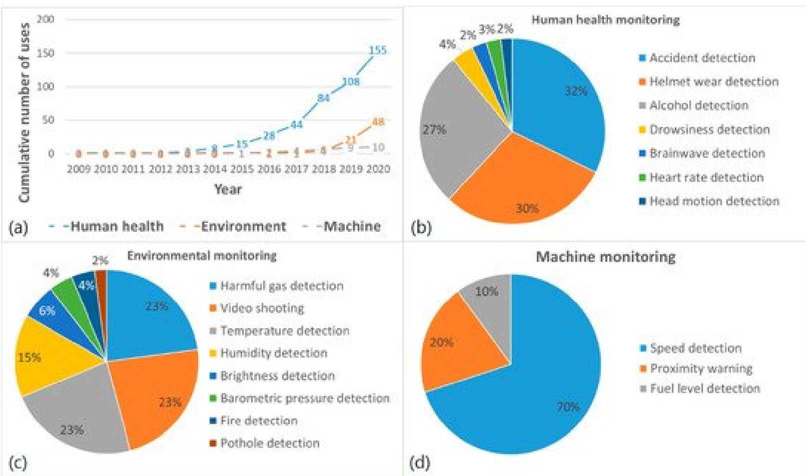

Figure 6. Trend of sensor uses in smart helmet studies. (**a**) Cumulative number of uses of sensor types according to year. Usage percentage of sensors for (**b**) human health monitoring, (**c**) environmental monitoring, and (**d**) machine monitoring.

Table 2. Types of sensor depending on the purpose used in smart helmet studies.

Types of sensor depending on the purpose used in smart helmet studies.

Human Health Monitoring	Environmental Monitoring	Machine Monitoring
- Accident detection (50 papers)	**- Harmful gas detection (11 papers)**	**- Speed detection (7 papers)**
- Helmet wear detection (46 paper)	**- Video shooting (11 papers)**	**- Proximity warning (2 papers)**
- Alcohol detection (42 papers)	**- Temperature detection (11 papers)**	**- Fuel level detection (1 papers)**
- Drowsiness detection (6 papers)	**- Humidity detection (7 papers)**	
- Brainwave detection (4 papers)	**- Brightness detection (3 papers)**	
- Heart rate detection (4 papers)	**- Barometric pressure detection (2 papers)**	
- Head motion detection (3 papers)	**- Fire detection (2 papers)**	
	- Pothole detection (1 papers)	

5. Types of Microcontroller Used in Smart Helmets

Different types of microcontroller have been used to develop smart helmets. By analyzing 103 articles, this study classified the microcontrollers into four categories.

- Chip modular concept unit (MCU): a single computer chip designed for embedded applications (e.g., PIC 18F8720) [110]

- Single-board MCU: a microcontroller built onto a single printed circuit board (e.g., Arduino) [111]

- Single-board computer: a complete computer built on a single circuit board, with microprocessor(s), memory, input/output, and other features required for a functional computer (e.g., Raspberry Pi) [112]

- Smart device: an electronic device, generally connected to other devices or networks by means of different wireless protocols that can operate to some extent interactively and autonomously (e.g., smartphone) [113]

The number of studies that used each of the four types is presented in Figure 7. Among the 103 articles analyzed in this study, the single-board MCU was the most used (56 studies), followed by the chip MCU (28 studies). The number of single-board computers and smart devices used was relatively small (11 and 8 articles, respectively). The use of single-board MCUs has increased rapidly since 2016. Although there have not been many uses of single-board computers so far, their use for smart helmets has increased since 2017. The use of smart devices has been minimal, which is believed to be because of the relatively high cost compared with other devices.

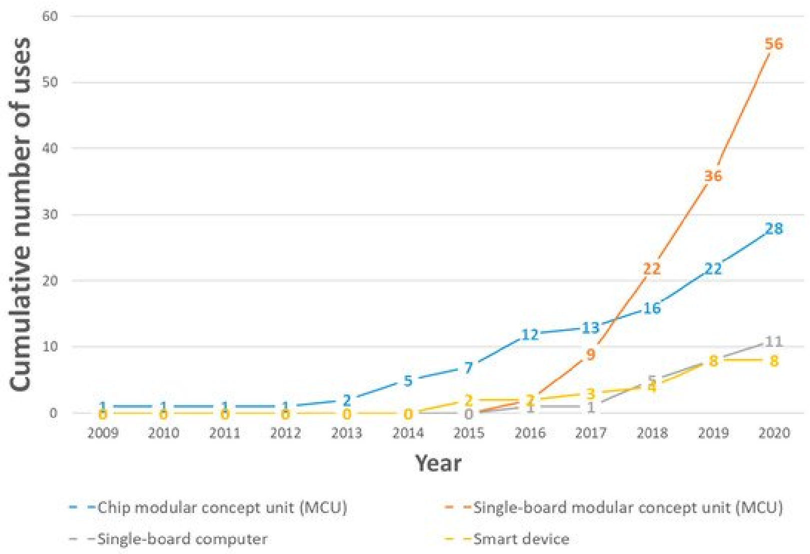

Figure 7. Cumulative number of microcontrollers used in smart helmet studies by year.

Figure 8 shows the use of sensors according to the type of microcontroller in smart helmet studies. Accident, helmet wear, and alcohol detection sensors have been frequently used with the chip MCU and single-board MCU. As shown in Figure 6, the uses of accident, helmet wear, and alcohol detection sensors make up a large part of smart helmet applications. Therefore, it is judged that the uses of chip MCU and single-board MCU were rapidly increased due to the increased development of smart helmets for accident, helmet wear, and alcohol detections. In the case of using a sensor that processes a large amount of data such as video shooting, it can be seen that a single-board computer or a smart device is being used. If the use of sensors based on images or videos increases in smart helmet studies, the single-board computers or smart devices are expected to be used more as microcontrollers.

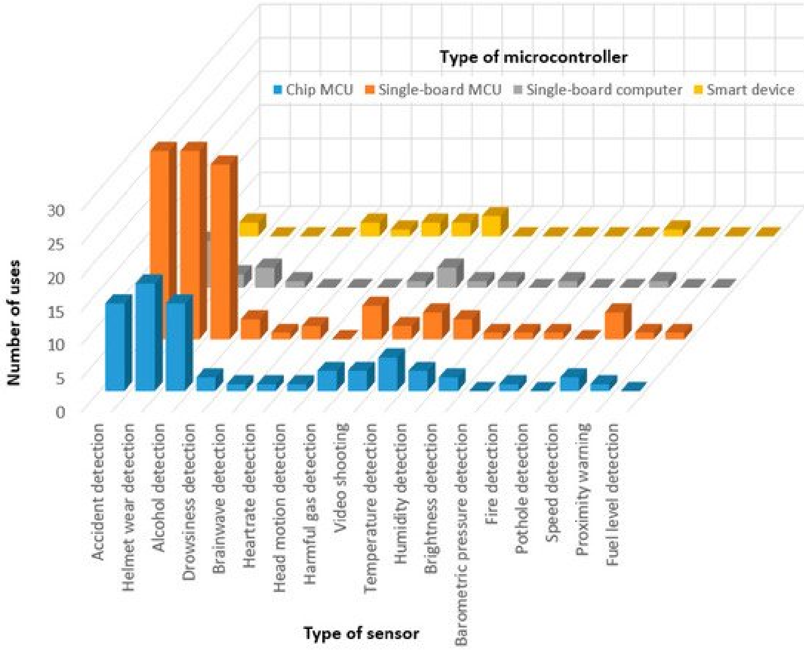

Figure 8. Number of uses by sensor and microcontroller types in smart helmet studies.

6. Types of Wireless Communication Technology Used in Smart Helmet Studies

The data obtained from smart helmets can be transmitted to other smart devices or cloud servers using several wireless communication technologies. Of the 103 articles, 88 reported studies that used wireless communication technology, such as RF, Bluetooth, Wi-Fi, and Zigbee for this purpose, whereas the remaining did not. Figure 9 shows the cumulative number of uses of wireless communication technology by year for sharing data from smart helmets. According to the analysis results, RF and Bluetooth were the most commonly used, and the number of uses has been increasing rapidly since 2015. Zigbee has been used for the longest time; however, its usage has not increased significantly until recently.

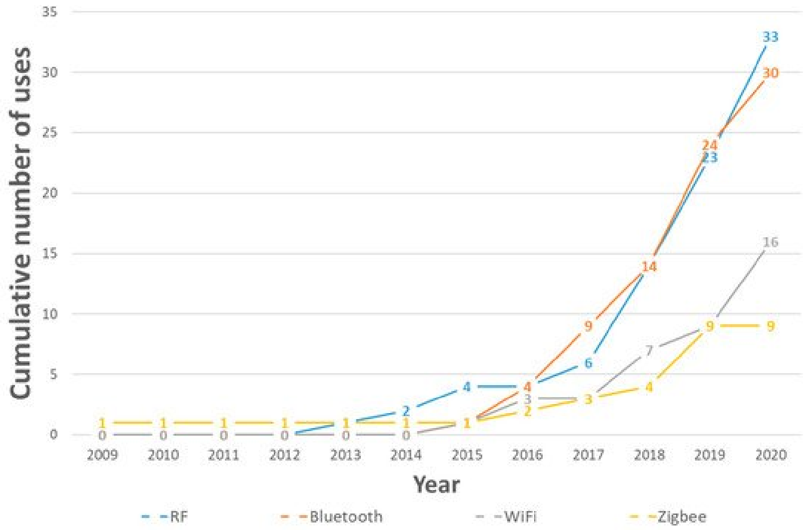

Figure 9. Cumulative number of wireless communication technologies used in smart helmet studies by year.

The reason why RF and Bluetooth are used frequently is related to the microcontroller used in smart helmet applications. Until now, the chip MCU and single-board MCU have been mainly used for smart helmet development, and these two types of microcontrollers often use RF and Bluetooth as shown in Figure 10. In the future, as the use of single-board computers increases, the frequency of use of Wi-Fi is expected to increase. In addition, the uses of Bluetooth and Wi-Fi may increase when the use of smart devices increases in smart helmet studies.

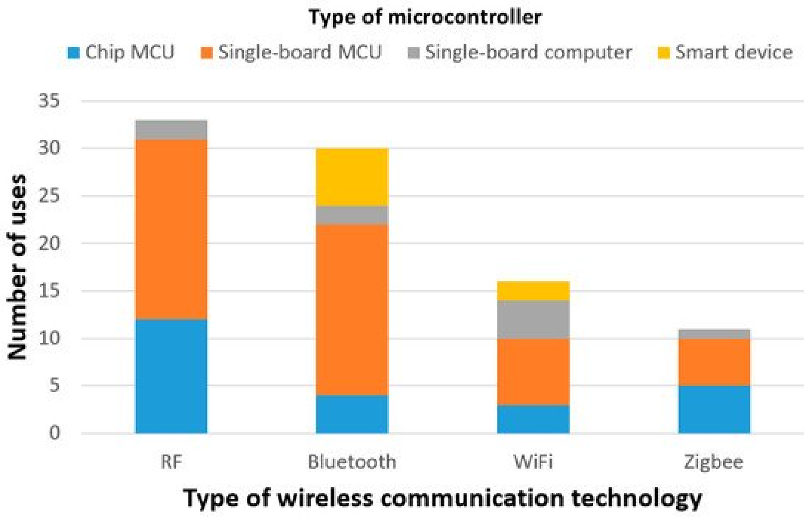

Figure 10. Number of uses by wireless communication technology and microcontroller types in smart helmet studies.

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