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Review

Applications of Smart Helmet in Applied Sciences: A Systematic Review

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Abstract: A smart helmet is a wearable device that has attracted attention in various fields, especially in applied sciences, where extensive studies have been conducted in the past decade. In this study, the current status and trends of smart helmet research were systematically reviewed. Five research questions were set to investigate the research status of smart helmets according to the year and application field, as well as the trend of smart helmet development in terms of types of sensors, microcontrollers, and wireless communication technology. A total of 103 academic research articles published in the past 11 years (2009–2020) were analyzed to address the research questions. The results showed that the number of smart helmet applications reported in literature has been increasing rapidly since 2018. The applications have focused mostly on ensuring the safety of motorcyclists. A single-board-based modular concept unit, such as the Arduino board, and sensor for monitoring human health have been used the most for developing smart helmets. Approximately 85% of smart helmets have been developed to date using wireless communication technology to transmit data obtained from smart helmets to other smart devices or cloud servers.

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

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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 [10–109]; 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. Research Methodology

In this study, the systematic review was designed using five steps as follows.

(1) Research questions were defined to conduct a systematic review of smart helmets.
(2) A search method was designed to identify academic research articles related to the research questions.
(3) Selection criteria were set to distinguish between articles related to the research questions and those not related to them.
(4) The selected articles were analyzed, and the results were integrated.
(5) The results were summarized and reported to provide answers to the research questions.

2.1. Definition of Research Questions

Five research questions (RQs) were defined to review the current status and trends of smart helmet research.

- RQ1: How is the trend of publications related to smart helmet research by year and source?
- RQ2: In which fields has the smart helmet research been mainly conducted?
- RQ3: What kinds of sensor have been mainly used for smart helmet applications?
- RQ4: What types of microcontroller have been primarily used to develop smart helmets?
- RQ5: What kinds of wireless communication technology have been mainly used to connect smart helmet with other devices?

2.2. Literature Search and Selection

Related academic articles were initially searched and identified using the Web of Science, Scopus, and Google Scholar databases. The initial search keyword "smart helmet" was used, which provided numerous articles. Another search was conducted using such keywords as "Sensor", "IOT," "Arduino," and "Raspberry Pi." A total of 125 articles were found. Four selection criteria were established and used for the 125 articles. The selection criteria excluded the articles when (i) the article was duplicate, (ii) the article was not an academic research report, (iii) the article was not a full-text article, and (iv) information about microcontrollers was not clearly presented. Of these 125 articles, one article was excluded as a result of reviewing for duplicate articles. Six articles that were not academic research reports were excluded. Seven articles that were not full-text articles were excluded, and eight articles were excluded in which information about microcontrollers was not clearly presented. The final selection included 103 articles that met the selection criteria. For these 103 articles, a systematic review was conducted according to each research question. Figure 1 presents a flow chart of the selection criteria.

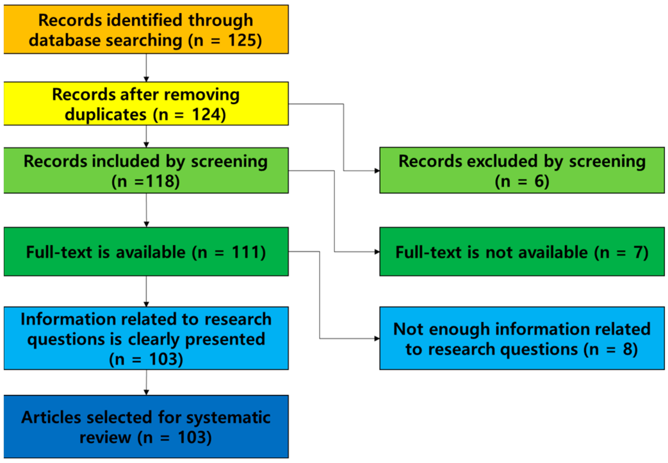

Figure 1. Flow chart of selection criteria.

2.3. Data Analysis and Outline of Results

The 103 articles obtained from literature selection were classified to separate contents of the articles and facilitate interpretation of the data. This analysis was conducted for each individual publication by considering the RQs and outline of the results presented in Table 1.

Table 1. Outline of results for each research question.

Year	Application Field		Sensor	Microcontroller	Wireless Communication Technology
2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020	Motorcyclist	- Start control - Accident prevention - Rescue request - Convenience improvement	- Human health - Environment - Machine	- Chip modular concept unit (MCU) - Single-board MCU - Single-board computer - Smart device	- Bluetooth - RF - Zigbee - WiFi
	Worker	- Mining - Construction - Petrochemistry - Disaster prevention - Medical treatment - General			

3. Results

3.1. 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%).

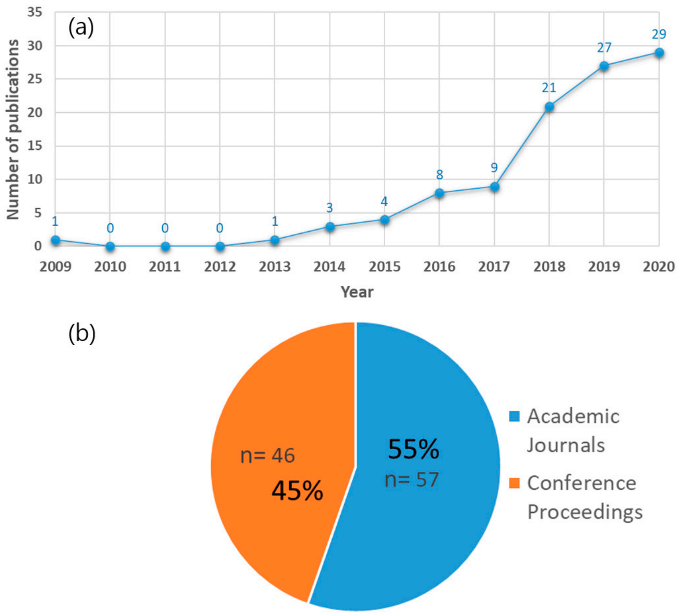

Figure 2. Number of publications related to smart helmet research by (**a**) year and (**b**) source of publications.

3.2. 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 3. Figure 4 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.

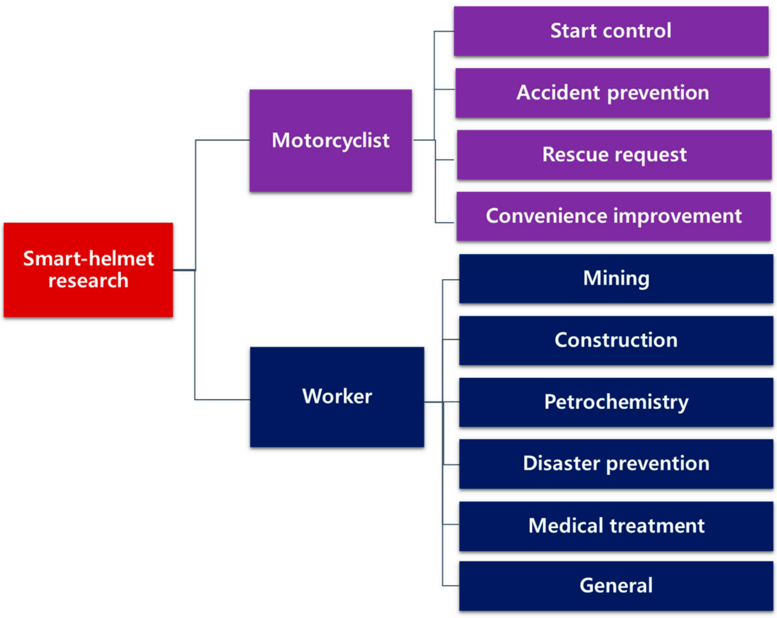

Figure 3. Classification of application fields in smart helmet studies.

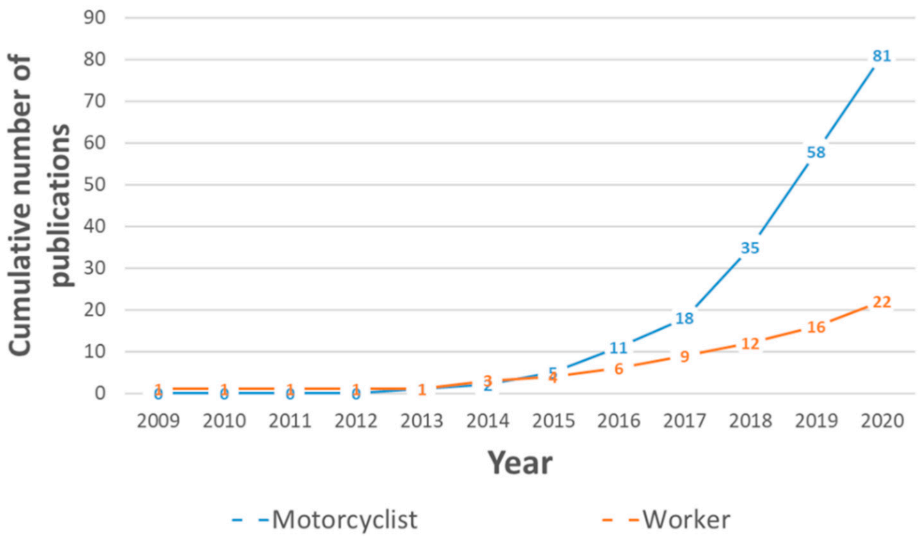

Figure 4. Cumulative number of publications by year in bike, occupational safety, disaster prevention, and medicine fields.

The applications of smart helmets for motorcyclists consist of 81 studies that account for the largest number of publications [7,10–80]. 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 5 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%).

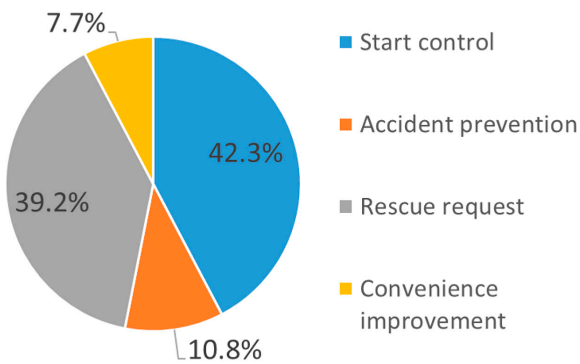

Figure 5. Percentage of smart helmet studies for motorcyclists by sub-category.

Table 2 summarizes the smart helmet applications reported in 81 studies for start control, accident prevention, rescue requests, and convenience improvement of motorcyclists. For the start control, the smart helmet checks whether the motorcyclist is wearing the helmet and for alcohol consumption. If any of the conditions are not met, the smart helmet controls the motorcycle to not start. For accident prevention, smart helmets are responsible for detecting drowsiness, speed and blinking, and providing warning alerts to prevent accidents. In the rescue request, the smart helmets detect a traffic accident and make a rescue request through text or phone calls in the event of an accident. Finally, for improving convenience of motorcyclists, the smart helmet provides them with several functions, including music play, phone calls, audio, and navigation.

Table 2. Summary of smart helmet applications for start control, accident prevention, rescue request, and convenience improvement of motorcyclists (MCU: modular concept unit).

Reference	Year	Feature and High-Level Functionality	Application (Sub-Category)	Sensor	Microcontroller	Wireless Technology
Singh et al. [7]	2019	Report potholes, collect air pollution data, and send it to a cloud server for analysis	Accident prevention	Porthole detection; Harmful gas detection	Smart device (Smartphone)	RF
Rasli et al. [10]	2013	Starts only when the helmet buckle is engaged, and warning is sent through the LED when over-speeding	Start control; Accident prevention	Helmet wear detection; Speed detection	Chip MCU (PIC)	RF
Vijayan et al. [11]	2014	Start-up management and accident prevention by collecting data on alcohol consumption and wearing a helmet	Start control	Alcohol detection; Helmet wear detection	Chip MCU (PIC)	RF
Agarwal et al. [12]	2015	Startup management by detecting whether a helmet is worn	Start control	Helmet wear detection	Chip MCU (Intel8051)	RF
Gautam et al. [13]	2015	Detects whether a helmet is worn or alcohol is consumed, and when both conditions are met, the engine starts up. Else, a text message is sent to a designated number when one of the conditions is not met or when an accident is detected	Start control; Rescue request	Helmet wear detection; Alcohol detection; Accident detection	Chip MCU (AT89S52)	RF
Melcher et al. [14]	2015	Collect vital signs to check the driver's condition and request rescue by phone or text in case of an emergency	Rescue request	Vital Sign detection	Smart device (Smartphone)	Bluetooth
Chandran et al. [15]	2016	Detects an accident and connects to the cloud server via WiFi; requests rescue from the emergency contact network	Rescue request	Accident detection	Chip MCU (CC3200)	WiFi
Magno et al. [16]	2016	Situational awareness, blinking, drinking, and temperature data are collected to ensure driver safety; low power modules allow the system to run for a long time	Accident prevention	Eye blink detection; Alcohol detection; Temperature detection	Chip MCU (MSP432)	RF
Nikharge et al. [17]	2016	Raspberry Pi image processing detects whether a helmet is worn	Start control	Helmet wear detection	Single board computer (Raspberry Pi)	
Jadhawar et al. [18]	2016	Detects whether a helmet is worn and drinking alcohol, and when both conditions are satisfied, the engine is started, and an accident is detected through a fall detection and a text message is sent to request rescue	Start control; Rescue request	Helmet wear detection; Alcohol detection; Accident detection	Chip MCU (ATMEGA32)	
Kim et al. [19]	2016	Rescue request by detecting an accident and sending a text message to the registered number	Rescue request	Accident detection	Single board MCU (Arduino)	Bluetooth
Kumar et al. [20]	2016	Detects whether a helmet is worn and alcohol is consumed. When both conditions are met, the engine is started, an accident is detected, and connection is made to the cloud server to request rescue through a mobile phone app.	Start control; Rescue request	Alcohol detection; Accident detection; Helmet wear detection	Single board MCU (Arduino)	WiFi

Table 2. *Cont.*

Reference	Year	Feature and High-Level Functionality	Application (Sub-Category)	Sensor	Microcontroller	Wireless Technology
Vashisth et al. [21]	2017	Detects whether the helmet is worn and if the driver is speeding in an inebriated state; if so, a text message is sent to request rescue in the event of an accident	Start control; Accident prevention; Rescue request	Helmet wear detection; Speed detection; Alcohol detection	Single board MCU (Arduino)	RF
Varade et al. [22]	2017	Detects whether the helmet is worn, sends the acceleration value to the cloud server for analysis, and requests rescue via text in case of an accident	Start control; Rescue request	Helmet wear detection	Chip MCU (ATMEGA16)	Bluetooth
Rajput et al. [23]	2017	Detects alcohol consumption, manages the start-up through fingerprint recognition, and sends a text message to the vehicle owner when the vehicle is stolen.	Start control	Alcohol detection	Single board MCU (Arduino)	
Patel et al. [24]	2017	Start-up management based on whether a helmet is worn, and an accident is detected and a text message is sent.	Start control; Rescue request	Helmet wear detection; Accident detection	Single board MCU (Arduino)	Bluetooth
Muthiah et al. [25]	2017	Introduction of autonomous headlight technology	Convenience improvement		Single board MCU (Arduino)	RF
Ahuja and Bhavsar [26]	2018	Vibration and shake sensors detect accidents and send voice messages and texts when they occur	Rescue request	Accident detection	Single board MCU (Arduino)	
Godwani et al. [27]	2018	Detects people's actions and shocks and sends text messages to family and acquaintances in case of an accident	Rescue request	Accident detection	Single board computer (Raspberry Pi)	WiFi
Parameshwari et al. [28]	2018	Detects whether a helmet is worn or drinking alcohol, and when both conditions are met, the engine starts up and a text message is sent in case of an accident.	Start control; Rescue request	Helmet wear detection; Alcohol detection; Accident detection	Single board MCU (Arduino)	Bluetooth
Biswas et al. [29]	2018	Detects an incident and sends an alert to nearby hospitals and other authorities by an app on your mobile phone connected to Google Firebase, which can be stopped via a PIN number	Rescue request	Accident detection	Single board computer (Raspberry Pi)	Bluetooth
Budiman et al. [30]	2018	Detect whether a helmet is worn and over speeding	Start control; Accident prevention	Helmet wear detection; Speed detection	Single board MCU (Arduino)	
Uniyal et al. [31]	2018	Collects helmet wearing status, location, speeding, and collision data; sends it to the cloud server; and requests rescue from nearby emergency facilities in case of an accident	Start control; Accident prevention; Rescue request	Helmet wear detection; Speed detection; Accident detection; Location detection	Single board MCU (Arduino)	RF
Paulchamy et al. [32]	2018	Detects whether a helmet is worn or alcohol is consumed; starts the engine when both conditions are met; collects location information; and sends text messages in case of an accident	Start control; Rescue request	Helmet wear detection; Alcohol detection; Accident detection	Single board MCU (Arduino)	RF
Souza and Maliyakal [33]	2018	Start management by detecting whether a helmet is worn	Start control	Helmet wear detection	Single board MCU (Arduino)	RF

Table 2. *Cont.*

Reference	Year	Feature and High-Level Functionality	Application (Sub-Category)	Sensor	Microcontroller	Wireless Technology
Nanda et al. [34]	2018	Collecting data, such as alcohol consumption, driver's license, blinking eyes, vibration, collision red light, etc.	Start control; Accident prevention; Rescue request	Alcohol detection; Driver's license detection; Eye blink detection; Accident detection	Single board computer (Raspberry Pi)	RF
Deva et al. [35]	2018	Start management by detecting whether a helmet is worn	Start control	Helmet wear detection	Chip MCU (ATMEGA16)	Bluetooth
Sumamah et al. [36]	2018	Detects an accident and send a text message in the event of an accident	Rescue request	Accident detection	Single board MCU (Arduino)	
Shabbeer and Meleet [37]	2018	Detects an accident, marks the location on the map, and sends a text message	Rescue request	Accident detection	Single board MCU (Arduino)	WiFi
Gudavalli et al. [38]	2018	By recognizing the RFID tag, it locks and unlocks to ensure security, and detects whether a helmet is worn to manage the boot	Start control	Helmet wear detection	Single board MCU (Arduino)	RF
Tapadar et al. [39]	2018	Detects alcohol consumption, helmet-wearing status, and accidents; collects data; learns it by machine learning with the SVM model; and then measures the accuracy	Start control; Rescue request	Alcohol detection; Helmet wear detection; Accident detection	Single board MCU (Arduino)	Bluetooth
Premalatha and Nandhini [40]	2018	Detects drinking and accidents and sends text messages in case of accidents	Start control; Rescue request	Alcohol detection; Accident detection	Chip MCU (PIC)	RF
Dhulavvagol et al. [41]	2018	Detects drinking and accidents and sends text messages in case of accidents	Start control; Rescue request	Alcohol detection; Accident detection	Single board MCU (Arduino)	WiFi
Joshi and Joshi [42]	2019	Start-up management by collecting data on drinking, speeding, and wearing a helmet	Start control; Accident prevention	Alcohol detection; Speed detection; Helmet wear detection	Chip MCU (PIC)	RF
Namayala [43]	2019	Start-up management by collecting data on drinking alcohol and wearing a helmet	Start control	Alcohol detection; Helmet wear detection	Single board MCU (Arduino)	RF
Wong et al. [44]	2019	Collect and analyze data on driver's head movement	Accident prevention	Head motion detection	Smart device (Smartphone)	
Kinage and Patil [45]	2019	Drinking and speeding are prevented, and drowsiness detection programs are applied through a webcam to prevent drowsy driving.	Start control; Accident prevention	Alcohol detection; Speed detection; Drowsiness detection	Single board MCU (Arduino)	
Swathi et al. [46]	2019	Start-up management by detecting alcohol consumption and helmet-wearing status, and ensures security with a password system	Start control	Alcohol detection; Helmet wear detection	Chip MCU (Atmega8)	RF
Reddy et al. [47]	2019	Detects alcohol consumption and helmet-wearing status, and sends a text message in case of an accident	Start control; Rescue request	Helmet wear detection; Alcohol detection; Accident detection	Single board MCU (Arduino)	ZigBee
Shravya et al. [48]	2019	Detects whether the helmet is worn, starts the engine, detects alcohol consumption, locks the engine, and transmits the vehicle number nearby via SMS text	Start control; Rescue request	Helmet wear detection; Alcohol detection; Accident detection	Single board MCU (Arduino)	RF

Table 2. *Cont.*

Reference	Year	Feature and High-Level Functionality	Application (Sub-Category)	Sensor	Microcontroller	Wireless Technology
Kanimozhi et al. [49]	2019	Start-up management by detecting whether a helmet is worn, alcohol is consumed, and heart rate is normal	Start control	Helmet wear detection; Alcohol detection; Heart rate detection	Single board MCU (Arduino)	RF
Patil et al. [50]	2019	Detects whether the helmet is worn, locks it, and detects an accident by detecting a fall; sends this information via text to the registered number	Start control; Rescue request	Helmet wear detection; Accident detection	Chip MCU (Atmega88p)	RF
Jesudoss et al. [51]	2019	Detects whether a helmet is worn and alcohol is consumed, and starts the engine when both conditions are met.	Start control	Helmet wear detection; Alcohol detection	Chip MCU (PIC)	ZigBee
Kabilan et al. [52]	2019	Vibration sensor detects an accident and sends a text message to the location of the accident	Rescue request	Accident detection	Single board computer (Raspberry Pi)	WiFi
Ashwin and Yashwanth Gowda [53]	2019	Detects whether a helmet is worn and drinking alcohol, and when both conditions are met, the engine is started and a text message is sent in case of an accident	Start control; Rescue request	Helmet wear detection; Alcohol detection; Accident detection	Chip MCU (Atmega32)	RF
Chen et al. [54]	2019	Collision detection by analyzing driver's head motion	Rescue request	Head motion detection	Smart device (Smartphone)	Bluetooth
Gupta et al. [55]	2019	Detects collision and drinking, requests rescue through text messages in case of an accident, and acts as a black box through a camera module	Start control; Rescue request	Alcohol detection; Accident detection	Single board computer (Raspberry Pi)	Bluetooth
Priya et al. [56]	2019	Detects whether a helmet is worn, manages the boot, detects an accident with vibration, and sends a text message	Start control; Rescue request	Helmet wear detection; Accident detection	Chip MCU (PIC)	RF
Vijayakumar et al. [57]	2019	Detects whether a helmet is worn and drinking, and notifies the driver of the presence of nearby vehicles through motion detection	Start control; Accident prevention	Helmet wear detection; Alcohol detection; Motion detection	Single board MCU (Arduino)	RF
Divyasudha et al. [58]	2019	Accident, location, and alcohol are detected and sent to the cloud server for analysis	Start control; Rescue request	Alcohol detection; Alcohol detection; Location detection	Single board MCU (Arduino)	ZigBee
Mhatre et al. [59]	2020	Detects whether a helmet is worn and drinking alcohol, and when both conditions are met, the engine starts and a text message is sent to the designated number in case of an accident	Start control; Rescue request	Helmet wear detection; Alcohol detection; Accident detection	Single board MCU (Arduino)	RF
Lakshmanachari et al. [60]	2020	Detects whether a helmet is worn, drinking, or speeding, and sends a text message in case of an accident	Start control; Rescue request	Helmet wear detection; Alcohol detection; Speed detection; Accident detection	Chip MCU (ARM7)	RF
Merlin and Pranay [61]	2020	Detects whether the helmet is worn and sounds the buzzer until the helmet is worn	Start control	Helmet wear detection	Single board MCU (Arduino)	RF
Chidambarathanu et al. [62]	2020	Collects brainwave and drinking data and sends location information via text in case of an accident	Start control; Rescue request	Brainwave detection; Alcohol detection; Accident detection	Single board MCU (Arduino)	Bluetooth

Table 2. *Cont.*

Reference	Year	Feature and High-Level Functionality	Application (Sub-Category)	Sensor	Microcontroller	Wireless Technology
Santhanakrishnan et al. [63]	2020	Detects whether or not to wear a helmet and drinking alcohol, and when both conditions are met, the engine is started and location information is sent by text in case of an accident	Start control; Rescue request	Helmet wear detection; Alcohol detection; Accident detection; Location detection	Single board MCU (Arduino)	RF
Sai Kumar and Aruna [64]	2020	Detects whether a helmet is worn, and when not wearing a message, a message is displayed through the LCD, and a text message is sent to detect alcohol and accidents	Start control; Rescue request	Helmet wear detection; Alcohol detection; Accident detection	Chip MCU (PIC)	ZigBee
Suman et al. [65]	2020	Detects drinking alcohol and wearing a helmet and sends a text message in case of an accident	Start control; Rescue request	Alcohol detection; Helmet wear detection; Accident detection	Chip MCU (TICC2200)	WiFi
Ahmed et al. [66]	2020	Detects objects, detects danger, and sends text messages in case of an accident	Rescue request	Object detection; accident detection	Single board computer (Raspberry Pi)	WiFi
Dubey et al. [67]	2020	Detects whether a helmet is worn; monitors road conditions to help change lanes; and sends a text message in case of an accident	Start control; Rescue request	Helmet wear detection; Accident detection	Single board MCU (Arduino)	
Lokeshwaran et al. [68]	2020	Detect wearing a helmet, measures your heart rate, and makes a call in case of an accident	Start control; Rescue request	Helmet wear detection; Accident detection; Heart rate detection	Single board MCU (NODEMCU)	RF
Rahman et al. [69]	2020	Detects drinking and wearing a helmet, stores location information, and transmits location information in case of an accident	Start control; Rescue request	Helmet wear detection; Alcohol detection; Accident detection; Location detection	Single board MCU (Arduino)	Bluetooth
Faikul et al. [70]	2020	Prevents drowsy driving by detecting heart rate	Accident prevention	Heart rate detection	Single board MCU (Arduino)	
Rao et al. [71]	2020	Detects wearing of a helmet and drinking, manages the start-up, and sends location information via text message	Start control; Rescue request	Helmet wear detection; Alcohol detection; Accident detection; Location detection	Single board MCU (Arduino)	WiFi
Oviyaa et al. [72]	2020	Brainwave is measured to detect drowsiness and fatigue and give a warning	Accident prevention	Brainwave detection	Single board MCU (Arduino)	Bluetooth
Shahare et al. [73]	2020	Detects wearing a helmet, manages the start-up, detects alcohol consumption and accidents, and sends location information by text in case of an accident	Start control; Rescue request	Helmet wear detection, Alcohol detection; Accident detection; Location detection	Single board MCU (Arduino)	RF
Ashwini et al. [74]	2020	Detects wearing a helmet, manages the start-up, detects drinking and accidents, and sends location information by text in case of an accident	Start control; Rescue request	Helmet wear detection; Alcohol detection; Accident detection; Location detection	Single board MCU (Arduino)	RF
Jayasinghe and Arachchige [75]	2020	Detects alcohol and drowsiness and manages start-up	Start control; Accident prevention; Rescue request	Alcohol detection; Drowsiness detection	Single board MCU (Arduino)	Bluetooth

Table 2. *Cont.*

Reference	Year	Feature and High-Level Functionality	Application (Sub-Category)	Sensor	Microcontroller	Wireless Technology
Aravinda et al. [76]	2020	Detects wearing a helmet and manages the start-up	Start control	Helmet wear detection	Single board computer (Raspberry Pi)	RF
MohanaRoopa et al. [77]	2020	Start management by detecting drinking, wearing a helmet, and sending location information by text in case of an accident	Start control; Rescue request	Helmet wear detection; Alcohol detection; Accident detection; Location detection	Single board MCU (Arduino)	WiFi
Pothirajan and Mary [78]	2020	Detects drinking and wearing a helmet	Start control	Helmet wear detection; Alcohol detection	Single board MCU (Arduino)	RF
Swarna et al. [79]	2020	Detects alcohol and manages the start-up and sends location information via text message in case of an accident	Start control; Rescue request	Alcohol detection; Location detection	Single board MCU (Arduino)	RF
Parakkal et al. [80]	2020	Detects speeding and sends location information via text in case of an accident	Start control; Accident prevention; Rescue request	Speed detection; Location detection	Single board computer (Raspberry Pi)	WiFi
Kumar Kar et al. [81]	2018	Convenience is provided through systems such as headlights and audio	Convenience improvement	Location detection	Single board MCU (Arduino)	Bluetooth
Rahman et al. [82]	2019	Detect fuel level and notify through notification system	Convenience improvement	Fuel level detection	Single board MCU (Arduino)	Bluetooth
Jadhav et al. [83]	2019	Provides convenience, such as navigation, traffic conditions, music, and phone calls, through voice recognition on the HUD by connecting a mobile phone	Convenience improvement	Location detection	Single board MCU (Arduino)	Bluetooth
Youssef et al. [84]	2019	Provides thermal comfort when wearing a helmet	Convenience improvement	Humidity detection; Temperature detection	Single board MCU (Arduino)	Bluetooth
Rao [85]	2019	A system that can operate the helmet wiper through voice recognition	Convenience improvement	N/A	Single board MCU (Arduino)	Wifi
Kanetkar et al. [86]	2020	Detects raindrops and automatically controls the helmet's wiper	Convenience improvement	Rain detection	Single board MCU (Arduino)	N/A
Astif and Manoj [87]	2017	Convenience such as navigation and listening to music is provided, and a text message is sent by pressing a button in case of an accident	Rescue request; Convenience improvement	Location detection	Single board MCU (Arduino)	Bluetooth
Ajay et al. [88]	2017	Provides convenience functions while driving and voice calls in case of an accident	Rescue request; Convenience improvement	Accident detection	Single board MCU (Arduino)	Bluetooth
Kumar et al. [89]	2019	By connecting to a mobile phone, it provides convenience, such as phone calls, navigation, and listening to music, and detects alcohol consumption	Rescue request; Convenience improvement	Alcohol detection	Single board MCU (Arduino)	Bluetooth

For example, in this category, Kanimozhi et al. [49] developed a smart helmet using a single board-based microcontroller (Arduino) with several sensors for detecting alcohol gas (MQ3) and heart pulse of motorcyclists. The radio frequency (RF) module was used to transmit and/or receive radio signals between the smart helmet and motorcycle. The data were stored in a local storage medium because the helmet did not provide a function to share the data that it monitored with other users. Uniyal et al. [31] developed a smart helmet using the Arduino board, RF transmitter, and sensors for detecting helmet wear, speed, accident, and location. The smart helmet collects and records speeding data of the bike and provides a risk warning when the bike exceeds the speed limit.

A total of 22 academic papers that deal with the applications of smart helmets for workers were published during the past 11 years [8,9,90–109] and are summarized in Table 3. The application fields include mining, construction, petrochemistry, disaster prevention, and medical treatment. Figure 6 shows the percentage of smart helmet studies conducted in each application field.

Table 3. 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

Table 3. *Cont.*

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
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

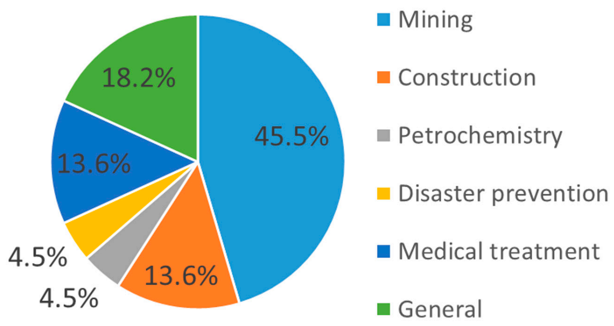

Figure 6. Percentage of smart helmet studies for workers by sub-category.

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 [90–99]. 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 [102–105]. 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.

3.3. Sensors Used for Smart Helmet Applications

Various sensors are attached to a smart helmet based on the application field and purpose. Table 4 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 7a. 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 7b–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.

Table 4. Types of sensor depending on the purpose used in smart helmet studies.

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

3.4. 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]

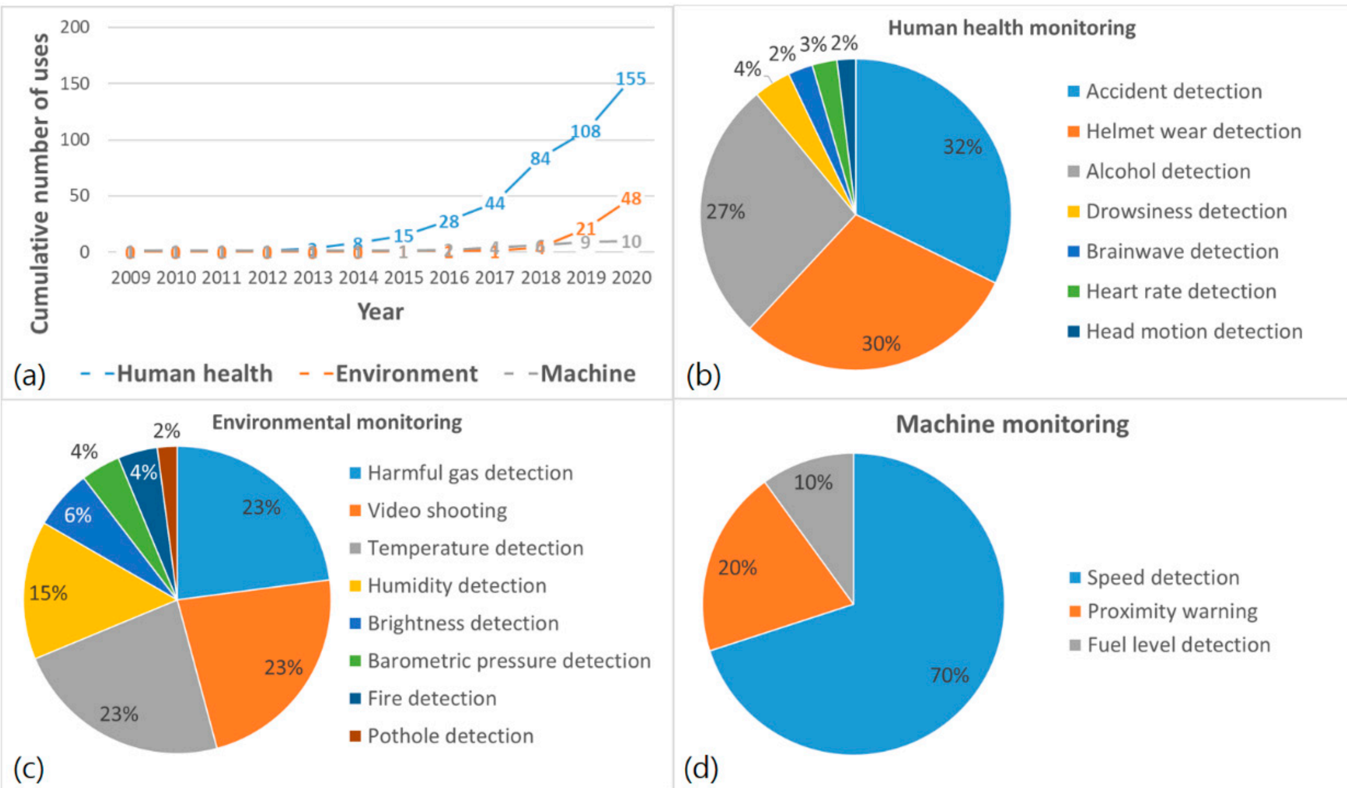

Figure 7. Trend of sensor uses in smart helmet studies. (**a**) Cumulative number of uses of sensor types according to year. Usage percentage of sensors for (**b**) human health monitoring, (**c**) environmental monitoring, and (**d**) machine monitoring.

The number of studies that used each of the four types is presented in Figure 8. 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.

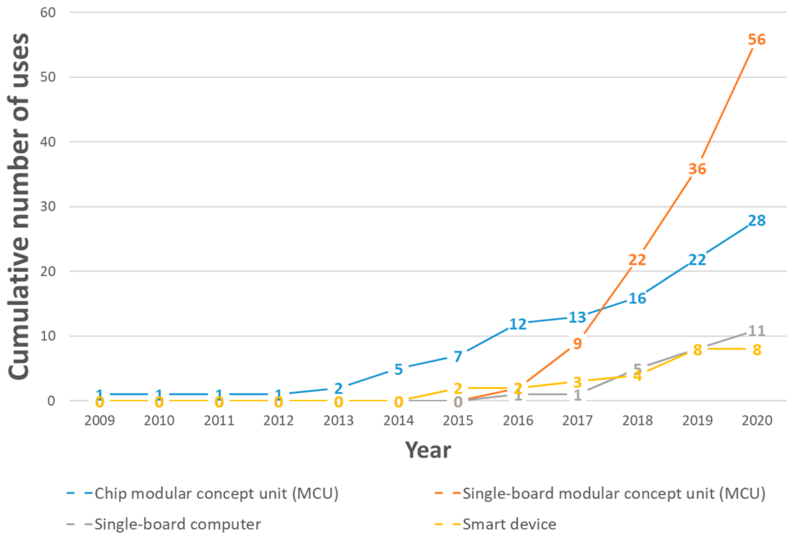

Figure 8. Cumulative number of microcontrollers used in smart helmet studies by year.

Figure 9 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 7, 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.

3.5. 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 10 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.

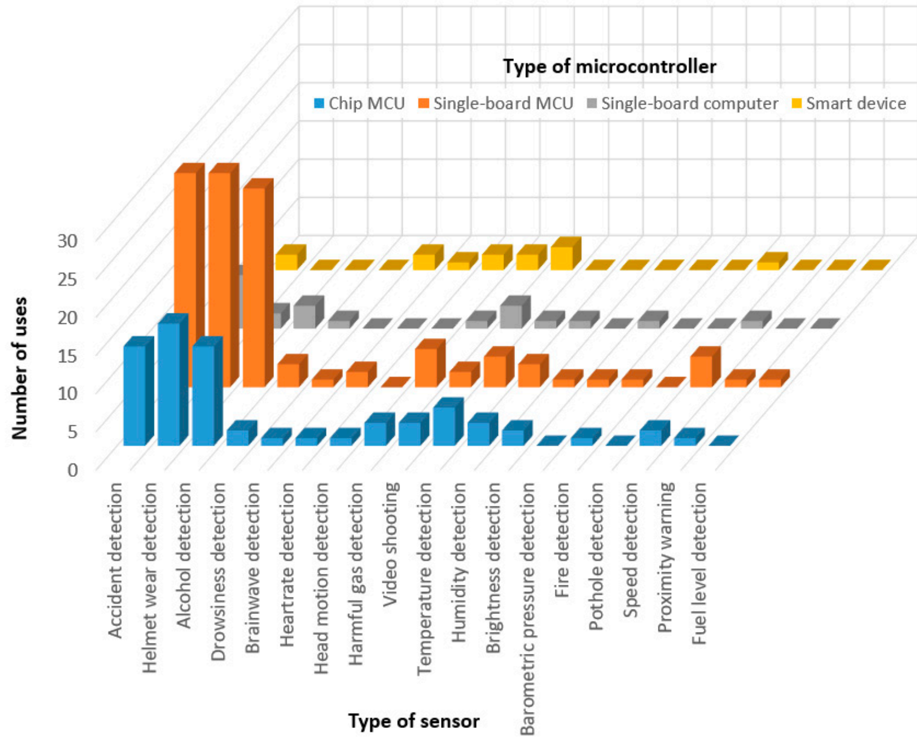

Figure 9. Number of uses by sensor and microcontroller types in smart helmet studies.

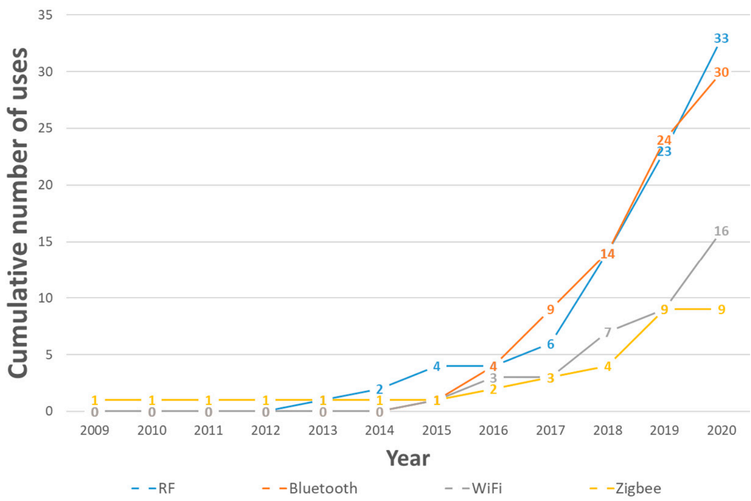

Figure 10. Cumulative number of wireless communication technologies used in smart helmet studies by year.

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 11. 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.

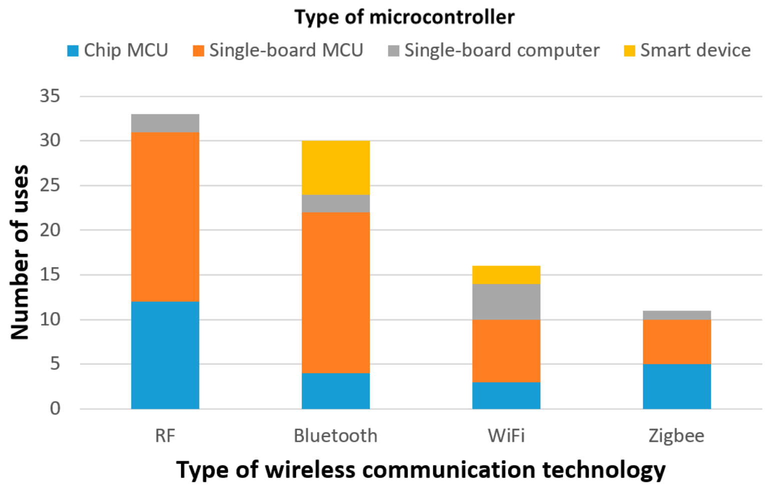

Figure 11. Number of uses by wireless communication technology and microcontroller types in smart helmet studies.

4. Discussion

In recent years, smart helmets have rapidly gained popularity among motorcyclists to enhance their safety and comfort. Moreover, safety regulations for workers are being strengthened in many countries; therefore, the growing adoption of advanced wearable technology, including smart helmets, is expected to drive the demand for personal safety. Based on this systematic review, the advantages and limitations of smart helmets can be summarized as follows.

Advantages of smart helmet

- Smart helmet is an intelligent and reliable wearable device with low costs of development and operation.
- Smart helmets can contribute to improving the safety of motorcyclists and workers by immediately detecting accidents and supporting rescue requests in emergency situations.
- Smart helmets are highly expandable and can be used in other applications by adding or removing sensors as needed.
- Smart helmets can be combined with wireless communication technology to secure the always-on connectivity of a device. Therefore, data can be acquired in real time from sensors attached to the helmet and transmitted to a cloud server for analysis.

Limitations of smart helmet

- Some sensors, such as cameras and global positioning systems attached to smart helmets have potential elements of privacy invasion. To date, there has been insufficient research on the security and privacy of data collected by smart helmets through sensors.
- Smart helmets mainly use inexpensive and lightweight sensors. Therefore, there is a possibility that the sensor malfunctions frequently, and a false alarm occurs.
- Various sensors can be attached to smart helmets, as needed; however, this can increase the helmet's weight and make it uncomfortable to wear. Moreover, attaching a large battery to power a smart helmet increases the load and can be dangerous to humans. Until now, little research has been conducted on the discomfort and health that people feel when wearing a smart helmet.

For future works, some challenges of smart helmets are as follows.

(1) Power consumption and battery life: As can be seen from the review results, power consumption is expected to increase as various sensors are being added to the smart helmet. Frequent charging and battery replacement can reduce the utility of the smart

helmet. Therefore, there is a need for a study on how to extend the battery operating time of a smart helmet by using low-power sensors and microcontrollers.

(2) Wearability: Smart helmets are relatively heavy compared to traditional helmets because a variety of sensors and microcontrollers are attached. Motorcyclists or field workers wearing heavy smart helmets may feel uncomfortable. In order for a smart helmet to provide its own functions as a wearable device, it is necessary to reduce the weight of the smart helmet by using lightweight materials and parts. Further research is required for this.

(3) Human health and safety: Because a smart helmet is worn on a person's head, research on the effect of the electromagnetic field emitted from a sensor or microcontroller on human health is required. In addition, it is necessary to consider the safety of the use of smart helmets in places where combustible gases may exist, such as underground mines and chemical facilities.

(4) Durability: Workers wearing smart helmets often work in high humidity and dusty environments. Smart helmets developed to date often have microcontrollers and sensors exposed to the outside of the helmet, and can be vulnerable to high humidity and dust. Research is needed to increase the durability of smart helmets so that smart helmets can provide functions even in harsh working environments.

(5) Accuracy: The sensors attached to the smart helmet should be small in size, lightweight, and low power consumption. Sensors that can meet these conditions at the same time may not have high measurement accuracy. Therefore, there is a need for research on a method that can improve the accuracy of measurement results while satisfying the sensor condition of a smart helmet.

(6) Privacy and data security: The smart helmet collects various information such as photos and videos according to the attached sensors. However, this collection of information can sometimes cause privacy concerns. In addition, there is a possibility of unauthorized users hacking the information in the stage of transmitting the data collected from the smart helmet. Therefore, the privacy and data security issues associated with the use of smart helmets are challenges that require continuous research.

(7) International standards: There are currently no international standards for smart helmets. In order to activate the development and distribution of smart helmets, it is necessary to consult and finance international standards for smart helmet specifications, functions, sensors, microcontrollers, wireless communication technology, etc.

5. Conclusions

A systematic review was conducted to investigate the current status and trends of smart helmet studies published in the past 11 years (2009–2020). The review provided answers to five RQs, as follows.

(1) The number of studies on smart helmets has increased rapidly since 2018. In the last three years (2018–2020), these studies accounted for 74.8% of the total number of studies. Therefore, it can be said that the research on smart helmets has been receiving considerable attention, and it is expected to be expanded further in the future.

(2) Studies on smart helmets can be divided into two categories (i.e., motorcyclists and workers) depending on the user. Among these, the application of smart helmets to motorcyclists accounts for 79%. Because helmets are necessary items that should be worn by motorcyclists, smart helmet studies have attracted relatively more attention in this field. Most smart helmets for motorcyclists provide functions for starting a motorcycle and rescue requests in emergency situations. To date, research on smart helmets for workers has been inadequate.

(3) Among the various sensors used for developing smart helmets, those related to human health monitoring have been used the most, and the last three years (2018–2020) have seen the highest increase. Among them, sensors for detecting accidents, helmet wearing status, and alcohol were frequently used, accounting for 32%, 30%, and 27%, respectively. Note that the use of environmental monitoring sensors for harmful gas

detection, image information acquisition, and temperature measurement, has rapidly increased since 2019.

(4) Currently, the type of microcontroller primarily used for developing smart helmets is a single-board MCU, such as the Arduino board, which accounts for more than 50% of all microcontroller types. Although single-board computers such as the Raspberry Pi or smartphones are also being used to develop smart helmets, this number has not been so far.

(5) To date, approximately 85% of smart helmets have been developed using wireless communication technologies, such as RF, Bluetooth, WiFi, and Zigbee. Among them, the use of RF and Bluetooth has been increasing rapidly since 2015, and they are the most commonly used technologies today, accounting for 38% and 34%, respectively.

Considering the expandability and functionality of smart helmets, they can be widely used not only for various sporting events but also for military purposes. However, until now, few cases of such applications have been reported in academic papers. Academic studies on smart helmets are needed to expand their application to more diverse fields, including sports and military services. Therefore, the findings of this study are expected to benefit researchers and industry professionals in various fields by offering detailed and systematic analysis results of smart helmet technologies to the community, thereby bridging the gap between academia and industry. In addition, it can help practitioners recognize the potential applications of smart helmets and understand the requirements and challenges of smart helmet products in various fields.

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