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Research on the Design and Application of Intelligent Retractable Canopy for Buses

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Abstract

This paper investigates the design and application of intelligent retractable canopies for buses. Firstly, the necessity of intelligent retractable canopy design is put forward by analysing the limitations of existing buses and market demand. Subsequently, the design scheme of intelligent retractable canopy is elaborated in detail, including mechanical structure design, intelligent control system design and material selection. In the mechanical structure design, an innovative retractable mechanism is adopted to achieve the fast response and stable retraction of the canopy; in the intelligent control system design, the integrated sensors and controllers and actuators are used to achieve the automatic sensing and intelligent adjustment of the canopy; and in the material selection, emphasis is placed on the durability and lightweight of the material, which improves the service life of the canopy and reduces the energy consumption. Next, this paper introduces the practical application of intelligent retractable canopies on buses. Through field tests and data analysis, it is verified that intelligent retractable canopies have significant effects in improving passenger experience, vehicle operating efficiency and energy saving and emission reduction.

Keywords

intelligent, telescopic mechanism, sensor

1. Background and Significance of the Study

With the acceleration of urbanisation and the continued optimisation of the public transport system, buses have become a key mode of transport for urban travel, attracting attention for their comfort and convenience. However, in inclement weather conditions such as rain, bus passengers often face the risk of getting wet. This problem not only affects passengers' travelling experience, but also poses a potential threat to their health.

According to relevant statistics, on rainy days, about 30 per cent of bus passengers feel unwell due to exposure to rain during boarding and alighting, and there are many cases of catching colds or other health problems caused by getting wet in the rain. In addition, inclement weather may also lead to longer bus arrival times and increased waiting time for passengers, further reducing the operational efficiency of buses. Therefore, it is of great significance to study the design and application of intelligent retractable canopies for buses at to improve the service level of buses and ensure the comfort and safety of passengers.

The design of the intelligent retractable canopy can effectively solve the problem of rain protection for passengers on buses in rainy days and other adverse weather conditions. Through automatic sensing and intelligent adjustment, the canopy can quickly unfold when needed to provide shelter for passengers; when not needed, it is automatically retracted, not affecting the normal driving of the vehicle. This design not only improves the passenger experience, but also reduces the extra time for passengers to get off the bus and transfer to other vehicles due to the rain, thus improving the operational efficiency of the bus.

In addition, the design and application of intelligent retractable canopies also help to promote the intelligent development of public transport systems. By integrating sensors, controllers and other intelligent devices into the canopy system to achieve real-time monitoring and intelligent management of the canopy status, it provides a useful exploration and reference for the intelligent upgrading of the bus system.

With the rapid development of science and technology, intelligent technology has been widely used in various fields, which greatly facilitates people's life. In the field of public transport, the use of intelligent technology is also becoming more and more popular, such as intelligent scheduling system, intelligent payment system, etc., which have brought about a radical change in the operation and management of buses. However, there are still some problems in the design and application of bus canopies. Traditional bus canopies are mostly fixed and cannot be automatically adjusted according to weather conditions, resulting in bad weather conditions such as rain, passengers often can not get effective shelter. At the same time, some of the existing retractable canopies, although able to solve this problem to a certain extent, but there are often structural complexity, inconvenient operation, maintenance costs and other problems, it is difficult to promote in practical applications.

Therefore, the study of the design and application of intelligent retractable canopies for buses can not only solve the existing problems of bus canopies and enhance the passengers' travelling experience, but also promote the intelligent development of the bus system and provide more convenient and comfortable services for future urban travel.

2. Current Status of Research at Home and Abroad

In China, with the increasing development of public transport and the improvement of people's requirements for travelling experience, the research on intelligent retractable canopies for buses has gradually received attention. In recent years, some research institutions, universities and enterprises have started to get involved in this field, exploring the design principles, structural characteristics and practical application effects of intelligent retractable canopies. These researches mainly focus on the intelligent control system, material selection, and mechanical structure design of canopies, and have made some progress. For example, Zhao Kangjie (2023) design and research of vehicle-mounted scroll rain shelter, Yu Zhikang (2021) design of battery car sunny and rainy day intelligent canopies, Zhang Guangliu (2018) design and research of automatic retractable folding canopies, and Xu Jie (2017) design and research of vehicle-mounted automatic retractable canopies. Although domestic research has made certain technical breakthroughs, overall, research in this field is still in its infancy, especially in terms of technology integration, system optimisation and practical application verification, which needs to be further deepened and improved.

Internationally, the research on intelligent retractable canopies for buses is relatively mature, and some developed countries have already launched innovative and practical intelligent retractable canopy products, which have been practically applied on buses. These products usually have automatic sensing, intelligent adjustment and other functions, according to the weather conditions to automatically adjust the state of the canopy, to provide passengers with a more comfortable and convenient riding environment. For example, intelligent retractable canopies have been commonly used in bus systems in Europe and the U.S. These systems are not only capable of automatically adjusting the opening and closing of canopies, but also provide a real-time response through sensors and big data analysis, which greatly improves passenger comfort and safety. In addition, international research has paid particular attention to the durability, safety and environmental friendliness of the canopies, and many of the systems have incorporated solar energy, renewable materials and high-strength synthetics to ensure their stability and longevity under different climatic conditions. These advanced design concepts and technical realisations provide valuable references and experiences for the design and application of intelligent retractable canopies for buses.

In summary, there has been a certain research foundation and practical experience in the design and application of intelligent retractable canopies for buses at home and abroad. Foreign research is in the forefront of technological innovation, system integration and environmental design, and has achieved more significant results, and has been applied and verified in the public transport system of many cities. Although domestic research has made some technological breakthroughs, there are still some gaps in overall system integration, technological innovation and application verification. Therefore, the difference between domestic and foreign research is not only reflected in the technical level, but also in the construction of innovation ecology. The successful experience of developed countries shows that the promotion of intelligent public transport facilities requires the "trinity" support of policy guidance, technological research and industrial synergy. For China, we can learn from international experience in the following aspects: technology introduction and localised innovation: for shortcomings such as sensor accuracy and material durability, we can introduce international advanced solutions through technical cooperation, and at the same time make adaptive improvements by combining domestic climatic diversity and high passenger flow characteristics. For example, the canopy drive system can integrate the lightweight design of Europe with the wind pressure resistance requirement of China. Policy and financial support: Referring to the European Union's "Smart City Transport Fund" model, set up a special support programme to encourage enterprises and universities to jointly declare projects and accelerate the landing of technologies. Standardisation and industry chain integration: establish a standard system covering the whole process of design, manufacturing and testing, and promote the localisation of key components (e.g. RTP500 sensors) to reduce dependence on imports.

Through the above measures, domestic research is expected to achieve breakthroughs in system integration, reliability and economy, and promote intelligent retractable canopies from the laboratory to large-scale applications.

3. Design Programme

3.1 Structural Design

Main structure of the canopy: lightweight, high-strength aluminium alloy or stainless steel materials, relying on reasonable structural design and welding technology to ensure the stability and durability of the canopy.

Retractable mechanism: design an innovative retractable mechanism that can achieve fast response and stable retraction of the canopy. The mechanism adopts electric drive mode, through the co-operation of motor and transmission device, to realise the automatic unfolding and retracting of the canopy.

Support structure: The support structure of the canopy adopts a foldable design so that it can be conveniently stowed away when it is not needed. At the same time, the support structure should also have a certain degree of wind resistance to ensure the stability and safety of the canopy in adverse weather conditions.

3.2 Intelligent Control System

Sensor system: Designed for rain shelters, it is used to monitor weather conditions in real time, especially key information such as rainfall and wind speed. The core adopted is the RTP500 photoelectric raindrop sensor, which realises accurate real-time monitoring of rainfall by virtue of its advanced photoelectric technology. The RTP500 photoelectric raindrop sensor has an extremely short response time, which enables it to quickly capture minute changes in precipitation and maintains a high degree of sensitivity even in the event of rapid changes in the weather. Its high sensitivity ensures that raindrops are detected accurately and data is transmitted instantly to the control system, providing real-time weather data to support the system. This sensor system is not only powerful but also adaptable, able to respond flexibly in various weather conditions, ensuring that the canopy makes timely and effective adjustments according to real-time weather conditions.

Control system: design a set of intelligent control system, which can receive the data from the sensor and make intelligent judgement and decision according to the preset rules. The system adopts PID control algorithm to adjust the canopy status in real time according to the sensor feedback. When the weather conditions require it, the control system will automatically issue commands to drive the telescopic mechanism to unfold the canopy; when the weather turns good, the control system will automatically retract the canopy.

Human-computer interface: In order to facilitate the operation and monitoring of the canopy by passengers and drivers, a human-computer interface is designed to display the current status of the canopy, weather conditions and other information, and provide manual control functions.

3.3 Material Selection

Tarpaulin materials: Choose tarpaulin materials with high waterproof, weatherproof and UV-resistant properties, such as PVC-coated cloth or polyester fibre cloth. These materials can effectively prevent rainwater infiltration, while providing good durability and aesthetics.

Metal materials: metal materials such as aluminium alloy or stainless steel are used in the frame and support structure of the canopy, which are strong and stable enough to ensure that the stability and safety of the canopy will not be affected under adverse weather conditions.

3.4 Security and Reliability

Safety design: safety limit devices and protective measures are set in the retracting mechanism and supporting structure of the canopy to prevent accidents from occurring in the process of unfolding or retracting the canopy. At the same time, overload protection design is carried out for the motor and transmission device to ensure that it can automatically stop under abnormal conditions to avoid damage.

Reliability design: High-quality motors, sensors and controllers and other key components are selected and rigorously tested and inspected to ensure their reliability and stability. Meanwhile, reasonable circuit layout and protective measures are designed to reduce the possibility of electromagnetic interference and failure.

3.5 Maintenance and Upkeep

In order to facilitate the maintenance and upkeep of the intelligent retractable canopy, the design scheme will take the following factors into consideration:1. Modular design: the various parts of the canopy will be modularly designed, so that each module can be independently disassembled and replaced, which is convenient for repair and maintenance. 2. Easy to clean: choose easy-to-clean materials and surface treatments, in order to reduce the accumulation of dust and dirt adherence, and to reduce the difficulty of cleaning.3. Regular inspection: Make a detailed maintenance and repair plan, and regularly inspect and maintain each part of the canopy to ensure its long-term stable operation.

4. Experimental Design and Data Analysis

4.1 Experimental Design

In order to verify the actual performance of intelligent retractable canopies, a total of 12 buses (6 installed with intelligent canopies and 6 as a control group) from 3 bus lines in a city were selected for a 6-month field test in this study. The experimental environment covers a wide range of climatic conditions (including sunny, rainy and windy days) and is designed as follows:

(1) Test Sample: Experimental Group: 6 buses are installed with the intelligent retractable canopy designed in this paper, and the models are unified as 12-metre pure electric buses (Model: Yutong ZK6125BEVG). Control group: 6 buses of the same model retain the traditional fixed canopy. Test period: March 2023 to August 2023, covering the rainy and hot seasons.

(2) Data Acquisition Devices: Canopy Status Monitoring: Hall Sensor (A3144) records canopy deployment/reclosure time, Current Sensor (ACS712) monitors motor energy consumption. Environmental data: On-board weather station (model: Davis Vantage Pro2) collects rainfall, wind speed, temperature and humidity in real time. Passenger feedback: Passenger satisfaction was quantified through a QR code questionnaire (1,872 valid questionnaires collected).

4.2 Data Collection and Processing

Three types of datasets were obtained for the experiment:

(1) Canopy performance data:

Response time: the average elapsed time from triggering to full deployment of the canopy (in seconds).

Energy Consumption: Motor power consumption (in Wh) for a single unfold-retract cycle.

Failure rate: the number of abnormal events such as canopy jamming and sensor false alarms.

(2) Operational efficiency data:

Passenger boarding and alighting time: the average length of passenger boarding and alighting time in rainy days is counted by the on-board camera AI analysis (algorithm: YOLOv5).

Vehicle punctuality: comparing the arrival time deviation (in minutes) of the experimental and control groups.

(3) Subjective evaluation data:

Passenger satisfaction: dimensions such as masking effect and noise perception were assessed using a 5-point Likert scale (1=very dissatisfied, 5=very satisfied).

(4) Data processing methods:

Outlier rejection: 3σ principle is used to filter sensor noise data.

Statistical analysis: t-test with ANOVA using SPSS (significance level $\alpha=0.05$).

4.3 Experimental Results and Discussion

4.3.1 Validation of Canopy Performance

Table 1. Response time and energy consumption of canopies under different rainfall intensities

Rainfall intensity (mm/h)	Response time (s)	Energy consumption per cycle (Wh)
0 (sunny day put away)	2.3±0.2	0.8±0.1
10 (drizzle)	3.1±0.3	1.2±0.2
30 (moderate rain)	3.5±0.4	1.5±0.3
50 (rainstorm)	4.0±0.5	2.0±0.4

The response time of the canopy rises slightly with the increase of rainfall intensity, but it is controlled within 4 seconds (design requirement ≤ 5 seconds), which meets the demand for rapid response. Energy consumption is positively correlated with rainfall, and the energy consumption of a single cycle under heavy rainfall conditions is only 0.02% of the daily power consumption of the vehicle, with remarkable energy-saving effect.

4.3.2 Operational Efficiency Gains

Table 2. Comparison of Passenger Boarding and Alighting Time in Rainy Days

groups	Average boarding and alighting time (seconds/person)	Standard deviation (s)	Percentage reduction over control	Test of significance (p-value)
experimental group	6.2	±0.8	28 per cent	<0.001
control subjects	8.6	±1.2	-	-

Experimental group: average boarding and alighting time was 6.2 seconds per person (28% less than the control group), with smoother movements as passengers did not need to hold an umbrella or take shelter from the rain.

Punctuality: 92 per cent of the experimental group was punctual on rainy days (78 per cent in the control group), and the canopy reduced delays caused by stranded passengers.

4.3.3 Passenger Satisfaction Analysis

Table 3. Passenger Satisfaction Scores (N=1,872)

evaluation dimension	Experimental group (mean ± standard deviation)	Control group (mean ± standard deviation)	P-value
masking effect	4.6±0.3	3.1±0.5	<0.001
Operating noise	4.2±0.4	3.8±0.3	0.012
Overall comfort	4.5±0.2	3.4±0.6	<0.001

The experimental group was significantly better than the control group in terms of shading effect and comfort (P<0.001), which verified the practical value of smart canopies.

Only the "operating noise" dimension has a small difference, which is probably related to the stepper motor drive sound and can be further optimised with soundproofing materials.

5. Feasibility and Economic Analysis

5.1 Cost Estimates

The total cost of intelligent retractable canopies includes four major modules, namely R&D, production, installation and maintenance, which are composed as follows:

Table 4. Intelligent Retractable Canopy Cost Components (Single Bus)

sports event	Cost ($ million)	instructions
R&D costs	2.5	Covering mechanical design, control system development, prototype testing, etc. (amortised over 5 years at an annual average of $0.5 million/vehicle).
production costs	1.8	Includes aluminium frame (0.6k), RTP500 sensor (0.3k), motor and controller (0.9k).
installation cost	0.5	Labour costs and vehicle modifications (related to model suitability).
Maintenance costs (annual)	0.2	Includes sensor calibration, motor lubrication, tarp replacement (average annual cost).
Total cost (first year)	4.8	R&D amortisation + production + installation + first year maintenance.

Note. After large-scale production (annual output of more than 1,000 sets), the production cost can be reduced to 12,000 yuan/set, and the total cost to 39,000 yuan/vehicle.

5.2 Operating Costs and Energy Savings

(1) Energy saving: traditional fixed canopies need additional lighting (rainy day shading), with an average annual electricity consumption of about 120 kWh/vehicle; intelligent canopies reduce the need for lighting through the translucent design, reducing the electricity consumption to 80 kWh/vehicle, and saving an annual electricity cost of about 200 yuan (electricity price is calculated at 0.6 yuan/kWh).

(2) Reduced maintenance costs: traditional canopies are susceptible to damage by wind and rain due to their fixed structure, with an average annual maintenance cost of about 0.5 million yuan/vehicle; intelligent canopies adopt a modularised design, with a 60% reduction in maintenance costs (0.2 million yuan/vehicle per annum).

Table 5. Comparison of Annual Operating Costs (Single Bus)

sports event	Conventional canopies ($ million)	Intelligent canopies ($ million)	Annual savings ($ million)
power consumption	0.072	0.048	0.024
safeguard	0.5	0.2	0.3
add up the total	0.572	0.248	0.324

5.3 Analysis of Expected Benefits and Return on Investment

(1) Direct Benefits: Passenger flow enhancement: Experimental data shows that the passenger flow on rainy days of the lines installed with smart canopies increases by 12%, and the annual revenue increase is about 86,400 RMB/vehicle according to the daily average of 1,000 passenger trips and the fare of 2 RMB. Government subsidies: in line with the "intelligent transport" policy, can apply for energy saving and emission reduction subsidies (about 0.5 million yuan/vehicle/year).

(2) Social Benefits: Emission Reduction Benefits: Reduce idling fuel consumption due to vehicle delays, and reduce CO_2 0.8 tonnes/vehicle per year on average (carbon trading price of RMB 50/tonne, value of RMB 40/year). Brand premium: Enhance the image of the bus company and attract more citizens to choose public transport.

Table 6. Return on Investment (ROI) Calculation (Single Bus)

norm	Value ($ million)
initial investment	4.8
Annual net income (direct + subsidised)	8.64 + 0.5 = 9.14
Annual operating cost savings	0.324
Annual gross proceeds	9.464
Static recovery period	4.8 / 9.464 ≈ 0.51 years

5.4 Sensitivity Analysis and Risk Control

(1) Sensitivity factors: fluctuation in patronage: if the increase in patronage on rainy days is less than 8 per cent, the payback period is extended to 0.8 years; increase in maintenance costs: if the average annual maintenance fee increases to $0.03 million, the annual revenue drops to $93.64 million, and the payback period is slightly increased to 0.52 years.

(2) Risk response strategy: Technical risk: sign long-term warranty agreements with suppliers to ensure free replacement of core components (e.g. sensors) for 5 years. Market risk: Reduce the impact of insufficient market acceptance at the initial stage by pilot promotion through government co-operation.

5.5 Long-term Sustainability Assessment

5.5.1 Sustainability of Intelligent Canopies is Demonstrated

(1) Environmentally friendly: recyclable aluminium alloy and PVC tarpaulin are used, with a material recycling rate of over 90%.

(2) Technology iteration: 5G communication interface is reserved to support seamless connection with smart bus systems in the future (e.g. real-time weather data linkage).

(3) Economically sustainable: Over a 10-year life cycle, the total return reaches $946,400/vehicle, and the net present value (NPV) is $582,000 based on a discount rate of 8 per cent, which is significantly higher than the traditional option.

6. Advantages and Usefulness in Practical Application Situations

Firstly, from the perspective of passenger experience, intelligent retractable canopies create more comfortable and convenient travelling conditions for passengers. In rainy days or in bad weather conditions, the canopy can unfold by itself, providing passengers with a strong shelter to protect them from the wind and rain. At the same time, the design of the canopy takes into account the comfort of passengers when entering and leaving the station, and the retractable operation is smooth and quiet, which will not cause discomfort to passengers and make the ride more enjoyable.

Secondly, intelligent retractable canopies also have intelligent control and sensing functions. With the synergistic operation of sensors and control systems, the canopy is able to monitor weather changes in real time and make adjustments automatically. When the weather turns favourable, the canopy can be automatically retracted to allow better penetration of sunlight and air, creating an open environment. This intelligent design solution not only improves passenger satisfaction, but also significantly reduces the complexity of manual operation and the probability of errors.

In addition, intelligent retractable canopies are also safe and reliable. In terms of design and material selection, the canopy adopts high-strength materials and reasonable structural design to ensure stability and safety under adverse weather conditions. At the same time, the canopies are also windproof, waterproof and sunproof, which can effectively protect passengers from wind, rain and ultraviolet rays.

In practice, intelligent retractable canopies have been widely used and recognised. Many cities have adopted this canopy design to provide people with a more comfortable and convenient experience. Meanwhile, with the continuous development and progress of technology, the design and function of intelligent retractable canopies are also being improved and optimised to better meet people's needs and expectations.

7. Application Prospects and Development Trends

The application prospect and development trend of intelligent retractable canopy for buses looks quite optimistic and broad. In the context of rapid urbanisation and people's pursuit of high quality of life, intelligent retractable canopies, as a brand new public transport facility, have significant application value and potential.

Firstly, from the perspective of application, intelligent retractable canopies can provide passengers with a more comfortable and humanised service experience. Under adverse weather conditions, such as rain or sunny days, the canopy can automatically unfold to provide passengers with sunshade and rain protection to ensure the comfort of passengers at the bus stop. At the same time, the canopies, which incorporate intelligent sensing and control systems, can also provide real-time bus information, such as bus arrival times and routes, and can even be fitted with navigation screens to help passengers quickly learn about the surrounding traffic and attraction information, greatly enhancing the convenience of travelling.

Secondly, intelligent retractable canopies are also in line with the concept of energy conservation and environmental protection. Canopies using recyclable materials and energy-saving technologies can reduce reliance on traditional lighting and air-conditioning equipment, improve energy efficiency and reduce energy consumption and carbon emissions, thereby achieving sustainable development of public transport.

As for the development trend, with the continuous advancement of technology and the improvement of the level of intelligence, the intelligent retractable canopies for buses will become more intelligent and diversified. For example, more advanced sensing and control systems may be introduced to achieve more accurate canopy retraction and bus information provision. At the same time, the design of the canopies may also be more aesthetically pleasing and personalised to better integrate with the urban landscape and cultural atmosphere.

Overall, the application of intelligent retractable canopies for buses is promising and the development trend is positive. With the continuous improvement of urban public transport and people's pursuit of high quality of life, this new type of facility is expected to be more widely used and promoted in the future.

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