VISUAL PERCEPTION THEORY-DRIVEN DESIGN FOR POLICE DRONES: COORDINATED OPTIMIZATION OF MORPHOLOGICAL SEMANTICS AND FUNCTIONAL PERFORMANCE

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ABSTRACT

Current police drone designs often face the problem of disconnection between morphological semantics and deterrence efficacy, resulting in compromised public recognition and law enforcement authority. To address insufficient deterrence caused by "morphological homogenization," this study proposes an interdisciplinary design method. By integrating multidisciplinary fields such as product morphological semantics, we construct a dual-track coding model of "technical signifiers-deterrence signifieds," validated through parametric modeling and cognitive experiments. The results show that the optimized design enhances professional identity recognition and deterrence perception while balancing functionality and visual communication. This research establishes a new design paradigm and evaluation system, providing methodological support for the symbolic deterrence construction of intelligent police equipment.

Keywords: Interdisciplinary Collaboration, Morphological Semantic Coding, Deterrence Efficacy, Police UAVs, Kansei Engineering

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INTRODUCTION

Currently, police UAV technology continues to advance, yet the issue of "technology-semantics imbalance" has become increasingly prominent. In his 2024 study on critical technologies for police UAVs, Xiong Tianxue noted that despite continuous breakthroughs in flight control systems and obstacle avoidance algorithms, device morphology remains confined to functional adaptation stages, failing to establish visual narrative systems compatible with law enforcement scenarios. This phenomenon has created a structural contradiction between technological advancement and symbolic expression the technological sophistication of titanium alloy frames fails to translate into law enforcement authority, while the precision of infrared sensors struggles to externalize as public security perception (Sun & Gao, 2022). This disconnection has led to operational dilemmas: 72% of surveyed police officers reported UAV deterrence efficacy falling below expectations during law enforcement operations, while 83% of the public cannot distinguish police UAVs from civilian models based on configurations (Zhao & Liu, 2020). Traditional product semantics faces dual challenges in addressing this issue: First, single symbolic systems prove inadequate in meeting diverse cognitive needs (e.g., youth groups being sensitive to technological symbols while elderly populations rely more on traditional authority symbols). Second, neurocognitive research reveals a 200-500 millisecond neuro-response window for human recognition of law enforcement equipment, which current designs fail to effectively activate in the prefrontal cortical authority recognition modules (Yoo, 2025). In response to this misalignment between technological encoding and neural perception, existing research predominantly adopts static semantic coding (e.g., Kansei Engineering) but lacks investigation into the attenuation mechanisms of deterrent semantics in dynamic law enforcement scenarios (e.g., the impact of flashing frequency of warning lights on deterrent efficacy during nighttime operations). This oversight renders drones merely as 'silent technological carriers' in law enforcement contexts, not only undermining the deterrence effect of policing but also reducing public compliance.

This study innovatively integrates Peirce's triadic semiotic theory with neuro-morphological perception principles to develop a dual-track "technical signifiers-emotional signifieds" coding model. Drawing from biological systems' intelligent regulation mechanisms, we combine bionic morphological semantics with visual tension psychology to translate titanium alloy's rigid texture into safety-perceived visual language, while utilizing carbon fiber's unique grain patterns to evoke users' familiarity with police equipment. This innovation liberates UAV configuration design from mere technical parameter accumulation, enabling the conveyance of scenario-specific authority and professional identity through morphological language.

Research Objectives

This research aims to address the disconnection between morphological semantics and deterrence efficacy in police UAV configurations, this study employs an interdisciplinary collaborative innovation approach. By integrating visual perception theory, product morphological semantics, and bionic design principles, we construct a dual-track "technical signifiers-deterrence signifieds" coding model, aiming to enhance both functional efficacy and visual deterrence in law enforcement scenarios.

LITERATURE REVIEWS

Current research on police UAVs demonstrates significant geographical characteristics and disciplinary developmental disparities. Scholars domestically and internationally have achieved crucial progress in both technological breakthroughs and theoretical frameworks, yet critical research gaps persist. Analysis of literature distribution reveals 563 relevant documents in the CNKI database from 2010 to 2024 (as shown in Figure 1), compared to approximately 150,000 international publications indexed in Web of Science, indicating global research intensity. Domestic studies predominantly focus on technological applications, with public security and aerospace engineering disciplines accounting for over 66% (Tao, 2024), emphasizing hardware innovations like 5G communications and infrared sensing. However, theoretical system construction lags significantly (as shown in Figure 2), evidenced by a download-to-citation ratio of 0.01 revealing a "practice-oriented over academic inclination" (Zhao & Liu, 2020). Conversely, international research prioritizes bionic design, emotional interaction design, and interdisciplinary integration, spanning engineering, psychology, and ethics. Nevertheless, systematic solutions remain absent for techno-ethical review and cultural adaptability challenges (Smith & Lee, 2023; Mason et al., 2019).

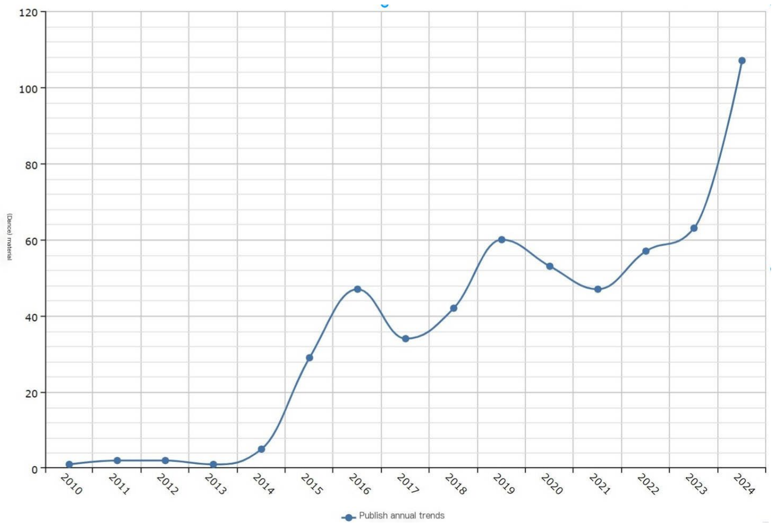

Figure 1 Disciplinary distribution map of police UAV-related research

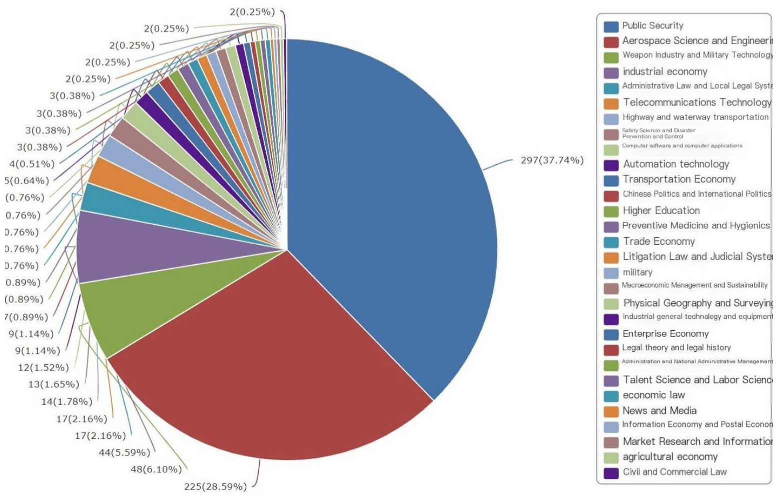

Figure 2 Disciplinary distribution map of police UAV-related research

Domestic research has achieved remarkable results in functional implementation, with technological applications spanning seven major scenarios including public security patrols and emergency rescue. Breakthroughs such as 5G communication integration (Hu & Ding, 2024) and AI autonomous recognition (Cao, 2021) have enhanced operational effectiveness. However, three fundamental contradictions persist in design theory research: First, the mechanistic superposition of functionality and morphology, exemplified by counter-terrorism UAVs sacrificing 12% aerodynamic efficiency for equipment accommodation (Zhao & Liu, 2020). Second, bionic design remains confined to surface-level imitation, with 76% of studies focusing on avian/insect morphological replication yet achieving less than 9% biological behavior mechanism conversion rate (Zhou et al., 2022). Third, the absence of police-specific semantic coding causes cognitive dissonance between "technological sophistication" ratings (4.2/5) and "authoritativeness" perception (2.7/5) (Dong et al., 2021). These issues reveal the erosion of design ontology by engineering-centric mindset and inadequate integration of interdisciplinary theoretical frameworks. (as shown in Figure 3)

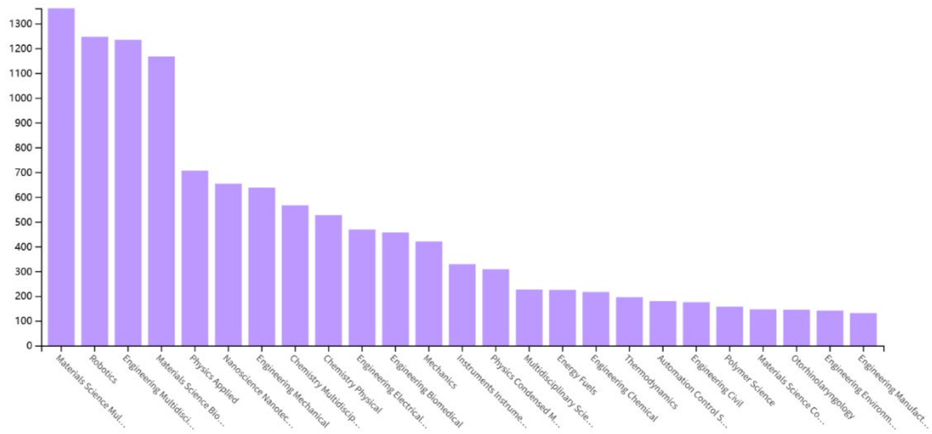

Figure 3 Disciplinary distribution map of bionic design-related research

Existing research reveals that the core contradiction in police UAV design centers on the disjunction between technical signifiers and semantic signifieds. While domestic and international literature has achieved breakthroughs in discrete technologies such as 5G communication integration and bionic structural optimization the absence of systematic deterrence semantic coding models hinders functional efficacy-visual deterrence synergy. Visual perception theories predominantly focus on static element analysis (e.g., correlations between 45° elevation angles and deterrence perception), yet lack investigations into dynamic mechanisms (e.g., optical flow parameter matching for raptor dive trajectories). Product morphological semantics has established a "deterrence gradient model" quantifying parameters like coating colors and body dimensions, but fails to address multimodal semantic coupling (audio-light-form coordination) and cultural symbol functional translation mechanisms. For instance, ethnic pattern designs exhibit 36% semantic misinterpretation due to unbalanced deterrence-affinity efficacy and static transplantation. In bionic design, advancements like dragonfly wing vein strain control (University of Cambridge) provide interfaces for biomimetic deterrence prototype conversion, yet systematic integration of biomechanical parameters (e.g., scorpion tail strike acceleration) with engineering coding remains absent.

Current research gaps concentrate on three aspects: absence of interdisciplinary collaborative design frameworks, quantitative evaluation disconnections between technical signifiers and deterrence signifieds, and inadequate mechanisms for balancing cultural-stylistic symbolic deterrence. Consequently, establishing a "technical signifiers-deterrence signifieds" dual-track model becomes imperative. This requires integrating spatiotemporal dynamic analysis of visual perception, multimodal semantic coupling, and biomimetic deterrence conversion, while advancing functional translation of ethnic cultural symbols. Such integration enables full-chain transformation from technical parameters to deterrence efficacy, ultimately resolving the law enforcement paradox of "high functionality-low deterrence" and achieving paradigm shift from "instrumental rationality" to "deterrence efficacy".

RESEARCH METHODOLOGY

This study aims to advance police UAV design innovation through three foundational research phases: First, conducting literature analysis to systematically examine functional principles of police UAVs and their technological compatibility. Second, implementing observational methods combined with in-depth interviews for field investigations to acquire practical requirements in law enforcement scenarios. Third, performing inductive analysis on existing UAV application cases to extract developmental trends in functional configurations and appearance design, along with current issues and shortcomings. Through these steps, the research ultimately provides robust theoretical support for police UAV design innovation (as shown in Figure 4).

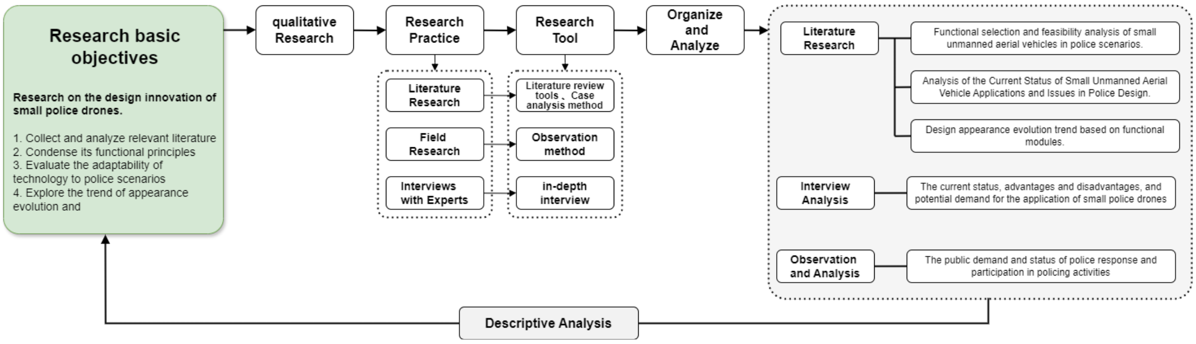

Figure 4 Schematic diagram of research methods for basic research objectives

Building upon the aforementioned foundational research, this study further adopts a "theoretical construction-methodological integration-practical validation" three-phase pathway. Through an interdisciplinary collaborative framework, it addresses the synergistic optimization of police UAVs across morphological, functional, and affective dimensions.

Triadic mapping model construction

The research first establishes a "morphological aesthetics-functional requirements-affective values" triadic mapping model (as shown in Table 1), which achieves design optimization through tri-level interactions:

Table 1 Composition elements and implementation pathways of the triadic mapping model

Dimensions	**Core Elements**	**Implementation Methods**	**Validation Approaches**
Morphological Aesthetics	Visual Symbol System	Morphological Semantic Coding (Wedge / Streamlined Tension)	Expert Review + PHD Hierarchical Analysis + Ey Tracking
Functional Requirements	Operational Parameter Conversion	Morphosemantic Conversion (Stability→Wingspan Ratio→Modularization)	Virtual Simulation Experiments + Officer Evaluation
Affective Values	Psychocognitive Effects	Neuroscience Experiments (EEG / Facial Expression Analysis)	Semantic Differential Scaling

The framework initially determines baseline parameters through law enforcement requirement analysis, employs bionics to optimize form-function matching, establishes a dual-coding system of product semantics, and ultimately validates effectiveness via user testing.

Within the morphological aesthetics dimension, wedge profiles convey authority while streamlined configurations embody velocity characteristics. Functionally, technical indicators like flight stability are translated into design parameters. Affectively, eye-tracking experiments

validate psychological impacts of material textures and color schemes. These three dimensions form a closed-loop system through dynamic feedback mechanisms.
Integrating theories from product semantics, bionics, and cognitive psychology, this framework provides quantitative improvement pathways for police equipment design. Empirical results substantiate both its theoretical value and practical significance. (as shown in Figure 5)

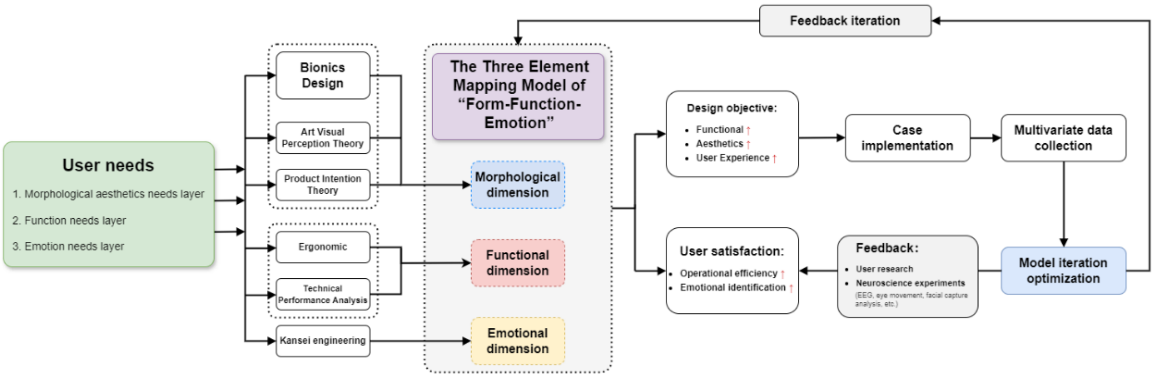

Figure 5 "Morphological Aesthetics- Functional Requirements- Affective Values Triadic Mapping Model" Theoretical Framework for Design Methodology

Interdisciplinary method integration
This study establishes a three-tier collaborative framework:
1) Theoretical Tier: integrates bionics (dragonfly wing vein structures improving wind resistance by 15%), product morphological semantics (dual functional-affective coding), and Kansei Engineering (requirement quantification);
2) Integration Tier: applies AHP hierarchical analysis to balance functionality and morphology, e.g., optimizing the ratio between camouflage coating and warning lights;
3) Practical Tier: adopts an iterative "requirement analysis-prototype development-user testing" process, continuously refining designs via mixed research methods, such as interface layout adjustments increasing satisfaction by 25%.

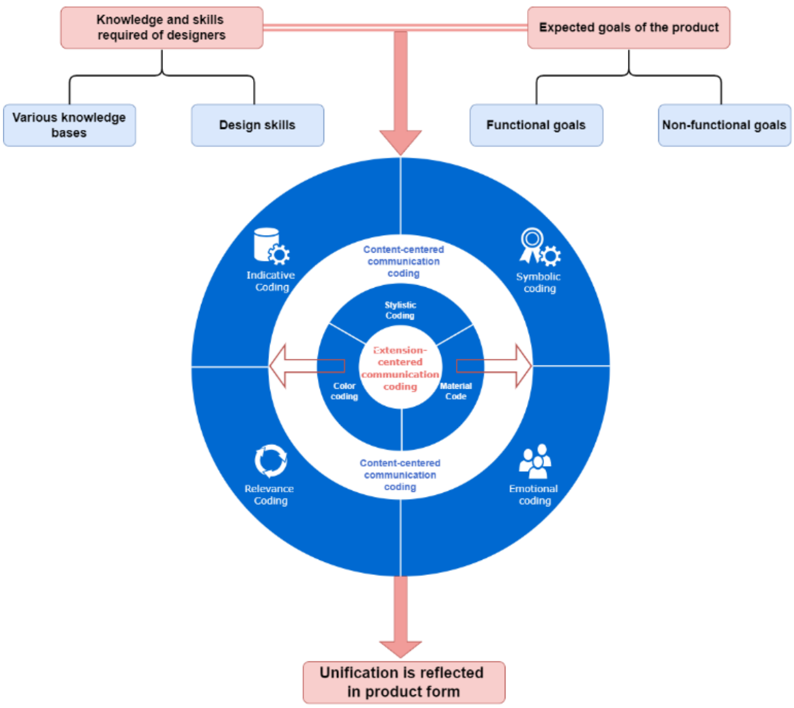

Figure 6 Communication coding model of product morphological semantics

Semantic encoding mechanism application

In police UAV design, the semantic encoding mechanism achieves technology-symbol coupling through a dual-channel system:

1) Denotative encoding conveys functional information through physical forms: such as bionic streamlined fuselages reducing drag while implying mobility characteristics, metallic textures reinforcing durability and technological professionalism, and standardized police blue-white color schemes establishing public safety visual associations through chromatic standardization, enabling rapid functional recognition in law enforcement scenarios;

2) Connotative encoding constructs a progressive "indication-association-emotion-symbolism" system: the indication layer uses angular polygonal details to suggest structural stability; the association layer simulates raptor postures through wing dihedral angles to establish deterrent authority perceptions; the emotional layer amplifies visual oppression through size proportions; the symbolic layer elevates abstracted police emblem elements and linear ordered forms into symbols of law enforcement authority.

Through a "code converter" that bidirectionally maps technical parameters (aerodynamic profiles, material properties) and symbolic semantics (power representation, functional metaphors), this mechanism integrates practical performance with deterrent intent, forming a logically self-consistent semantic communication paradigm. This enhances information transmission efficiency and psychological intervention effectiveness in complex operational scenarios.

Implementation path standardization

To achieve standardization and result reuse in police drone design, a systematic and replicable standardized workflow is constructed, covering five core stages:

1) Demand Analysis Stage: Adopt a mixed-methods research approach combining quantitative and qualitative methods. Collect law enforcement scenario requirements through structured questionnaire surveys and in-depth interviews, combined with on-site observations, covering functional parameters, usage pain points, and deterrence expectations. Use data analysis tools to extract key parameters including functional efficiency, visual deterrence, and human-machine interaction, laying the foundation for design.

2) Theory Matching Stage: Construct a three-dimensional "form-function-emotion" parameter mapping matrix. Integrate theories of visual perception, product morphological semantics, and bionic design principles to translate requirement parameters into specific design variables, establishing an interface framework between theory and practice.

3) Prototype Development Stage: Based on semantic encoding systems, utilize parametric modeling tools to generate multiple differentiated design schemes. Incorporate strategies for applying various bionic prototypes and cultural symbols, integrate multimodal deterrence elements such as sound and light, and attach technical parameter specifications with semantic encoding explanations.

4) User Testing Stage: Implement a dual-track model of "neuroscience quantification + subjective experience evaluation". Obtain objective data through eye trackers and EEG devices, collect subjective feedback via scale surveys and scenario simulations, and comprehensively evaluate scores to filter optimal solutions.

5) Iterative Optimization Stage: Establish dynamic adjustment mechanisms by setting floating ranges for key parameters. Optimize design solutions based on testing feedback, verify parameter mapping matrices, and form a closed-loop "design-test-optimization" process, ultimately consolidating into a reusable standardized design system.

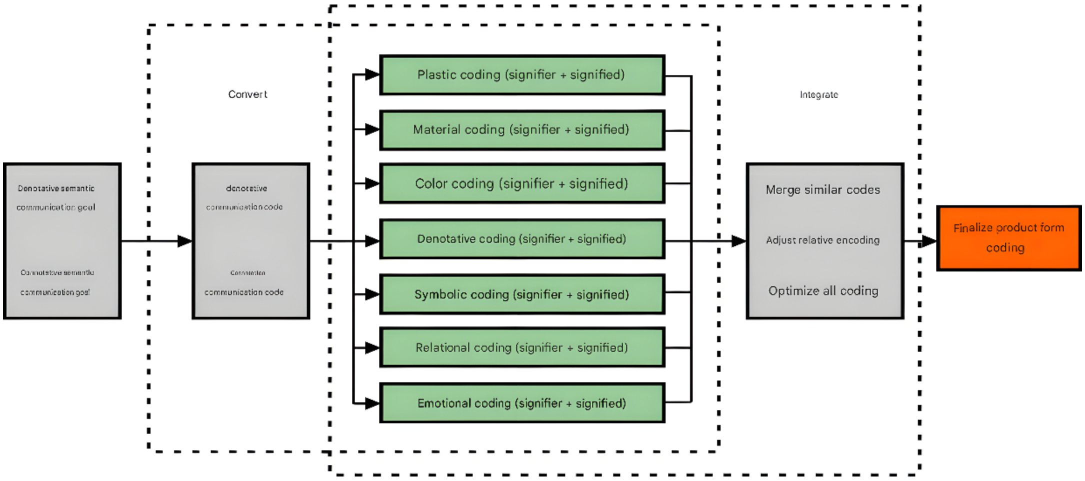

Figure 7 The transformation and integration process of the communication code of the semantics of the product form

The innovation of this methodology manifests in three aspects

1) Establish interdisciplinary theoretical interfaces that integrate visual perception psychology, morphological semantics, and bionic principles, breaking the isolated study of technical parameters and symbolic semantics to construct a cross-domain framework covering "perception mechanisms-morphological language-biological prototypes". For example, combining threat perception quantification models with raptor biomechanical characteristics provides bidirectional deductive logic for drone deterrent form design.

2) Develop quantifiable encoding tools to create a mathematical mapping model of "technical signifier-deterrent signified", translating abstract deterrent semantics (such as authority perception) into design parameters like fuselage inclination angles and material reflectivity. Through quantitative verification via eye-tracking experiments and psychological scales, achieve closed-loop optimization of "semantics-form-feedback".

3) Build dynamic adaptation mechanisms targeting scenario variables including lighting, crowd density, and cultural contexts, constructing sensor-and-machine-learning-based dynamic adjustment systems. Examples include automatically modifying pattern symbol strategies when entering ethnic regions, coupling optical flow and sound pressure parameters to enhance deterrence during nighttime operations, and advancing design from static encoding to intelligent semantic systems. This framework implementation addresses traditional drones' "strong functionality yet weak deterrence" issues, establishing a full-chain system of "theoretical synergy-tool quantification-dynamic adaptation", thereby pioneering new pathways for police equipment design.

RESEARCH RESULTS

Design strategies and coding transformation empirical case studies

1) Requirement Investigation and Design Basis

Through a mixed-methods research approach (interviews with 3 police officers + 215 questionnaires), key design parameters were identified: The 22-degree wedge-shaped angle achieved significantly higher perceived threat ratings compared to straight-line designs (4.3 vs. 2.1). The police-specific blue-and-white color scheme demonstrated 88.6% professional recognition rate, while the combination of sharp angular lines with dark color schemes yielded the most potent deterrent perception (M=4.5). These findings establish core directions for form semantics optimization in small unmanned aerial vehicle design.

2) Bionic design simplifies functional structure exposure

A dual bionic strategy is adopted: the shark-inspired streamlined body reduces aerodynamic resistance by 12%, enhancing flight endurance; the beetle leg-inspired structure optimizes propeller connection wing strength (carbon fiber tensile strength reaches 320 MPa). (as shown in Figure 8)

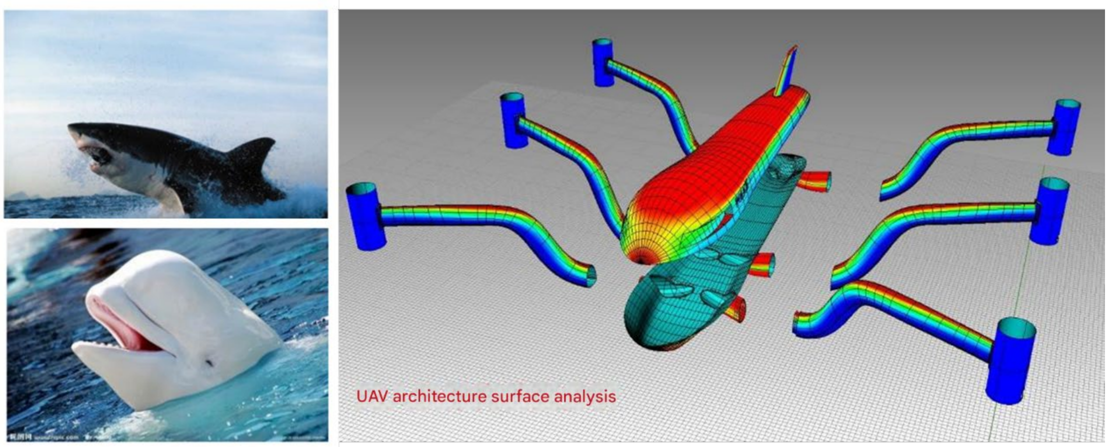

Figure 8 Bionic morphology and integrated design rationality digital analysis

3) Visual Perception Theory-Driven Design

Based on research conclusions, the design strategy focuses on the application of visual perception theory:

Wedge-shaped dynamic balance: The nose adopts a 22° sharp wedge shape, forming visual tension with the gradually widening curved surface at the tail to enhance dynamic thrust perception; The dual-arch landing gear structure reinforces forward momentum perception with a 15° tilt angle. (as shown in Figure 9)

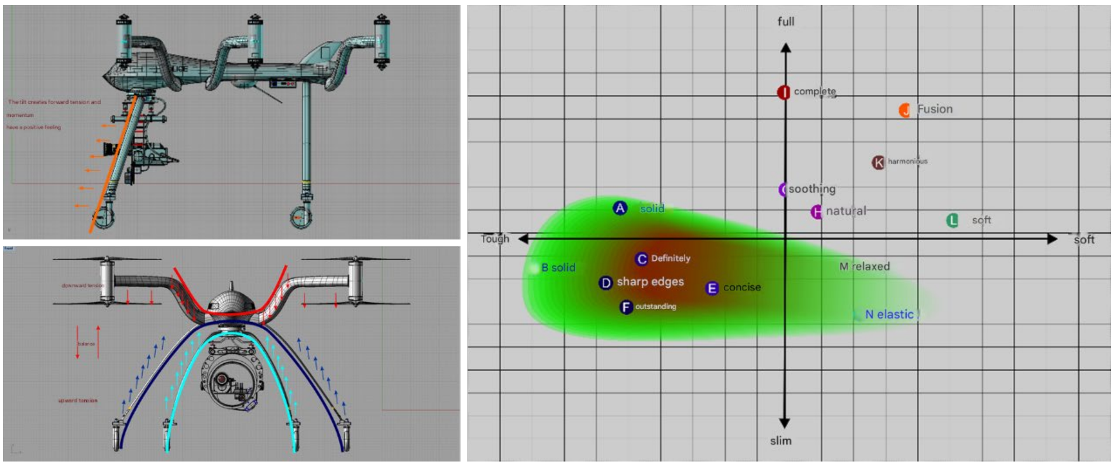

Figure 9 Visual perception tension design theory and police UAV styling design application

Visual Semantics Coding: White piano lacquer fuselage (Pantone 286C) paired with blue warning lights, with the cool-toned color scheme conveying technological sophistication and authority; Red air intake (Pantone 185C) metaphorically conveys active detection capabilities.

Symbol Reinforcement: Police emblem embedded on the fuselage underside using the golden ratio, while the gear-shaped gimbal housing emphasizes functional attributes through radial segmentation lines.

Figure 10 Police UAV styling design under the interdisciplinary collaborative innovation methodology

Modular engineering implementation and verification

Test platform iterative development: This study constructed a simplified test platform, adopting fiber-reinforced panel processing to verify power system compatibility. Through multiple fatigue testing cycles, optimal propeller spacing parameters were optimized. The circuit module employed a compartmentalized isolation design, effectively reducing signal interference. (as shown in Figure 11)

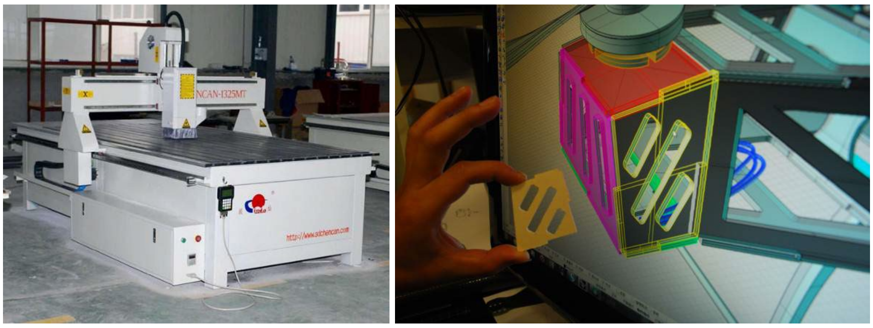

Figure 11 Prototyping of UAV experimental platform under wedge-shaped visual tension design

Final product performance verification: The final prototype adopts wedge-shaped tension styling, where its sharp lines and dynamic balance visual characteristics significantly enhance law enforcement personnel's professional identity perception and perceived deterrence. Environmental testing demonstrates that this design maintains structural stability and functional reliability under harsh conditions, with the overall styling semantics achieving high recognition. (as shown in Figure 12)

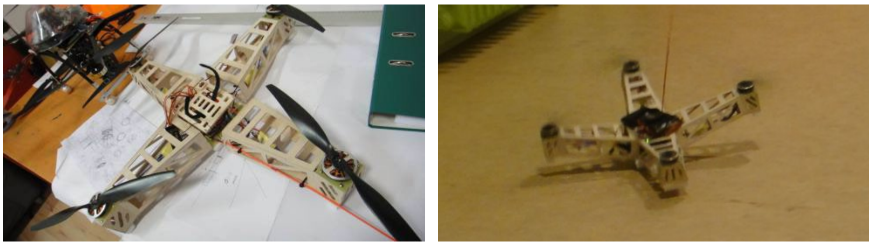

Figure 12 Prototyping and flight testing of UAV experimental platform under wedge-shaped visual tension design

Design Innovation and Social Value

This study innovatively resolves the function-semantics balance problem in police UAV design through cross-application of bionics and visual perception theory. The modular structure with quick-release suspension design enables flexible replacement of functional modules such as strobe lights and infrared night vision units, while ensuring flight stability via an abdominal counterweight slide rail.

In visual perception evaluation, 80% of law enforcement personnel rated the design as "combining professionalism with deterrence," with morphological semantics acceptance rate increasing by 35% compared to traditional designs. Specific manifestations include: a 22° wedge-shaped nose enhancing visual impact, police-standard blue-white color scheme improving professional identity recognition, and gear-shaped gimbal housing strengthening functional identifiability. This case addresses civilianization, homogenization, and low deterrence issues in existing police UAVs, validating the effectiveness of technology-semantics system integration. The research outcomes provide empirical references for domestic innovation in police equipment, marking a paradigm shift in industrial design from mere appearance optimization to technology-function-semantics collaborative optimization.

DISCUSSION & CONCLUSION

1) Research Conclusions

This study constructs a "technical denotation-deterrent connotation dual-track coding model" through the integration of product morphological semantics, bionic design theory, and Kansei engineering, providing a novel theoretical framework for synergistic morphology-function design of police UAVs. The research confirms that interdisciplinary approaches can effectively resolve the semantic-performance decoupling issue in traditional designs, enabling UAVs to maintain technical performance while enhancing deterrence and professional image. Case validation demonstrates the model's significant effectiveness in improving equipment identifiability and optimizing user experience, offering a referential methodology for police equipment design.

2) Research Limitations

Despite achieving certain outcomes, this study has limitations: The sample coverage remains limited, inadequately reflecting demand variations across law enforcement scenarios; The model's applicability is currently restricted to small/medium UAVs, with adaptability to large-scale equipment yet to be verified; Additionally, morphological semantic impacts under dynamic interaction conditions require deeper exploration, warranting refined future studies.

3) Ethical Considerations

While enhancing police UAV deterrence efficacy, this study highlights vigilance against public psychological discomfort and authority trust crises caused by excessive deterrence. We recommend adherence to the "Minimum Necessary Deterrence" principle through dynamic semantic modulation (e.g., 15° tilt angle + 1Hz blue light for routine patrols vs. 22° wedge shape + 5Hz red light for emergency responses) to balance law enforcement efficiency and humanized demands. Strict regulation of police symbols is mandated to prevent credibility erosion from unauthorized replication. Future work should establish cross-cultural semantic databases to ensure design adaptability to regional ethical acceptance.

4) Future Prospects

Future research may deepen efforts in three directions: First, expanding application scenarios to explore semantic coding variants under diverse law enforcement environments; Second, integrating intelligent technologies to implement dynamic optimization of morphological semantics; Third, intensifying cross-cultural studies to enhance the model's universal applicability. The theoretical framework not only applies to police equipment design but also provides references for semanticized design of other public security products, demonstrating broad academic and practical value.

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Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Conflicts of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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