https://doi.org/10.37420/j.eeer.2025.002

# Research on the Design of Police Robot Dog Utility Enhancement Based on STS Theory

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## Abstract

This study focuses on the utility dilemma of police robotic dogs in real-world applications, and systematically analyzes the synergistic imbalance between their technical and social subsystems based on the Science, Technology and Society (STS) theory. By integrating the feedback from police users and the STS theoretical framework, it reveals that there are core contradictions between the functional design of the current police robotic dog and the police demand, weak deterrence and arrest ability, and lagging system adaptation. The study proposes a two-way optimization scheme for technology and society: at the technical level, the modular hardware design, multimodal sensing system upgrade and deep reinforcement learning decision engine development improve the robotic arm's arrest accuracy (by 37%) and the stability of complex terrain movement (by 42%); at the social level, it builds a hierarchical specification for the use of force, and a human-machine collaborative tactical system, which reduces the risk of law enforcement disputes by 58%. Collaborative validation shows that the two-way optimization mechanism effectively bridges the gap between technical expectations and real-world effectiveness, providing an interdisciplinary solution for the deep police application of police robot dogs.

**Keywords:** police robot dog; STS theory; practical design; modular optimization; human-machine collaboration

# 1 Introduction.

In the process of intelligent development in the field of public security, police robots, as a product of multi-technology integration, are reshaping the police work mode. From the point of view of technical classification, police robots mainly include humanoid robots, wearable robots and patrol robots. Among them, humanoid robots adopt anthropomorphic design and can realize armed interaction, but the maturity of the technology is relatively low; wearable robots can enhance the physical ability of police officers and have high cost-effectiveness; patrol robots include wheeled, tracked and quadruped forms, which are mainly used for security monitoring and hazardous disposal tasks .

Quadrupedal robots belong to the category of bionic robots in a broad sense, and their core technical features are reflected in three aspects: bionic motion control algorithms based on animal gait dynamics models, multi-terrain adaptability to adapt to complex terrains such as rocks, stairs, and ruins, as well as modular sensor integration systems. As a subset of quadruped robots, robot dogs, by imitating canine locomotion mechanism and adopting purely mechanical mechatronic structure design, can realize functions such as autonomous patrolling, environment detection, and hazardous materials search. Taking Boston Dynamics' "Spot" as an example, this commercialized product not only possesses sensor integration capability, but also supports remote control operation.

This study focuses on the "Cyber Police Dog", i.e., police robotic dog, which was firstly put into practice by the Public Security Bureau of Yongkang City, Zhejiang Province, in December 2024, and has been given the Internet buzzword of "Cyber Police Dog". From the practical application point of view, pure mechanical robot dog (quadrupedal robot) has realized the technology landing, such as "Spot" has been in large-scale activities, security patrol, border patrol in complex terrain and other scenarios to carry out the pilot. However, this type of equipment still faces many challenges in practical application, and it is difficult to deeply integrate into the existing police process.

# 2 Review of existing research

## 2.1 Research status of police robots

Existing research shows that the technical system of police robots still has significant functional deficiencies: the feedback from frontline applications reveals the structural shortcomings of a single means of deterrence and a weak apprehension ability, and the environment sensing system often suffers from insufficient localization accuracy in complex terrain. This is consistent with the findings of Tran (2019) on urban search and rescue robots. Pure robotic solutions still belong to the "open research topics" that need to be broken through in terms of key capabilities such as traversing debris terrain and autonomous navigation in GPS-constrained environments.At the level of communication system, the problem of wireless signal blocking in complex environments is particularly prominent, forcing technology development to shift to the construction of emergency response mechanisms independent of real-time communication, such as the technology path presented by Tran's Canine Bark Triggered Material Delivery System (CRDS).

Similar to the police robot dog, the intelligent upgrading of the integration of police dogs and technical equipment has also stepped into the research field. Currently, the integration of technology presents a dual-track development: in terms of hardware integration, the "biological anti-terrorism robot system" proposed by Tang Ning (2009) creates a technical path combining police dogs and electronic equipment, realizing real-time audio-visual transmission and simple weapon operation through remote control, which to a certain extent circumvents the complexity of the structure of purely mechanical robots. The combination of police dogs and electronic equipment has created a technological path of combining police dogs and electronic equipment. Intelligent training field presents data-driven characteristics, Li Meng et al. (2021) developed the "intelligent training APP for working dogs" to realize the structured record of training data and the analysis of actual combat cases, effectively solving the traditional training "process, light results comparison" efficiency bottleneck. It effectively solves the bottleneck of traditional training "focusing on the process but not on the comparison of results"; the virtual simulation training platform constructed by Li Suxiong et al. (2023) improves the efficiency of training in special environments through the parameterized modeling of the scene.

Looking at the "human-machine-dog" cooperative system from the perspective of science, technology and society (STS) theory, its technological socialization process faces double constraints: at the institutional level, Roh et al. (2024) pointed out that the promotion of robotic police officers needs to firstly clarify the boundaries of the use of robotic police in order to avoid the ethical controversy of "excessive force", and the current situation is not suitable for the promotion of robotic police officers. At the institutional level, Roh et al. (2024) point out that the promotion of robotic police needs to first clarify the boundary of use to avoid the ethical controversy of "excessive force", and the current legal system has not yet formed a normative framework for the application of robotic dogs; Kemper & Kolain (2024) discuss the legal boundary by analyzing two quadruped police robots, and put forward the normative basis of lawful use; at the level of human-computer interaction, the "biomedicine" proposed by Braverman ( 2012) is a new concept. 2012) proposes a theory of "biotechnology" that reveals the essential differences between police dogs and robotic dogs. The active adaptability of canines in collaboration allows them to form a "mutually domesticated partnership" with humans. Robotic dogs, on the other hand, are still at the stage of pre-programmed response, and are unable to reproduce the tactical flexibility of biological vectors. This difference in technological metaphors directly leads to the lack of adaptability of robotic dogs in real-world combat scenarios, exposing a deeper disconnect between technological design and police needs.

## 2.2 Problem formulation

The current police robotics research has the outstanding problem of fragmented technical routes. Existing equipment features shallow characteristics, although it can undertake basic security tasks, but generally lack of deterrence, arrest and other core policing capabilities, dynamic confrontation scenarios in the lack of autonomous decision-making ability; AI-enabled level is still dominated by remote manipulation, the development of environment perception and autonomous emergency response mechanism lags behind, and there is a significant intergenerational gap with the demand for intellectualization.

Research on the integration of police dogs and technology is limited by the inherent limitations of biological carriers. The existing technology path is overly dependent on equipment superposition and training innovation, failing to break through the hardware constraints of load capacity and arithmetic, and the fluctuation of canine physiological state directly leads to the lack of system stability; there are obvious defects in the real-world data-driven mechanism, and the training data is disconnected from the real-world needs, and the intelligent management tools still remain at the record level, without forming the data-driven capability iterative system.

Police robotic dog research has a double fault line between academia and application. Academic field of pure AI quadruped robot in the police scene of the research is almost blank, the lack of theoretical support and technical paradigm; application practice stays in the "alternative manpower" at the primary stage, seriously ignoring the functional adaptability of the construction, can not reproduce the police dog "human-dog synergy" tactical capabilities, technical applications and real-world combat needs are not connected. Tactical ability of police dogs "human-dog cooperation", technology application and actual combat demand there is a deep disconnect.

To summarize, the research of police robotic dog needs to jump out of the pure technology framework, which can be based on the STS theory to integrate the technical design, drawing on the experience of intelligent police dog training for biological synergy, as well as institutional innovation to establish legal and operational norms. The future direction should focus on interdisciplinary optimization driven by real-world combat needs, bridging the gap between technical expectations and actual effectiveness.

# 3 Police User Feedback and Theoretical Analysis

## 3.1 Data sources

The study selected police personnel (including command staff and first-line operators) from the criminal investigation and security departments in many places to conduct semi-structured interviews, focusing on the use experience, functional evaluation and improvement needs of the robot dog in patrol and prevention and control, arrest operations, physical evidence search and other scenarios. Through the coding and analysis of the interview data, the core issues were refined.

## 3.2 Summarization of core issues

### *3.2.1 Symbolic application disconnected from police needs*

The current deployment of police robotic dogs is characterized by a significant "technical display priority", and its application scenarios are highly concentrated in large-scale events, administrative inspections and other ceremonial tasks. In this kind of scene, the robot dog is mostly put into use in the form of short-term lease, and the cycle of a single task is generally limited to a few hours to a few days, and it mainly undertakes the auxiliary functions such as static display and voice broadcasting. For example, in commercial exhibitions or public activities, robot dog is often used for interactive experience of science and technology, through dynamic walking, lighting sound effects and other visual presentation to attract the public's attention, but its actual participation in the police action stays in the formalized level. This application mode leads to machine dog long-term in the "show tool" rather than "combat equipment" positioning, difficult to deeply integrate into the existing police process.

From the functional adaptability point of view, the machine dog technical design and police practice needs there is a significant mismatch. Patrol scene, for example, although the machine dog can build three-dimensional maps and realize autonomous navigation through LiDAR, but its ability to respond to emergencies is still dependent on remote control, in the signal interference or complex terrain is prone to command delays. In addition, the modularity of the equipment under the rental mode is low, and it is difficult to quickly switch the hardware configuration according to the needs of different tasks, which leads to a lack of flexibility in responding to diversified police scenarios. This tendency of "heavy display, light combat" application essentially reflects the information asymmetry between the supply side and demand side of the technology - the developers focus on the advancement of technical indicators, while the front-line police personnel are more concerned about the reliability of the equipment and the adaptability of the task.

### *3.2.2 Shortcomings in Core Functions*

Firstly, there is a technical bottleneck in deterrence and capture capability. The deterrence mechanism of the existing robot dog mainly relies on non-physical means, such as voice warning and bright light irradiation, which makes it difficult to form substantial suppression in high-risk scenarios. The precision of its robotic arm operation is limited by the joint transmission structure and control algorithms, and the success rate of the control of the target in the dynamic environment is low. For example, in the simulated capture exercise, the robotic arm grasping action is susceptible to terrain bumps or target resistance interference, resulting in a higher mission failure rate. In addition, the movement stability of the robot dog has limitations in complex terrain, although its bionic quadrupedal structure can adapt to stairs, slopes and other terrain, but in the slippery road or sudden collision is prone to posture imbalance, affecting the continuity of task execution.

Secondly, the robot dog's ability to perceive the environment is not good enough to adapt to a variety of scenarios. In terms of odor recognition, physical evidence detection and other key functions, the adaptability of existing technology to complex scenes significantly lags behind biological police dogs. The environment perception of the machine dog mainly relies on vision and LiDAR data fusion, in the crowded, mixed odor environment, its recognition accuracy and real-time is difficult to meet the needs of the actual combat. For example, in the explosives detection scenario, the robot dog needs to analyze the substance through chemical sensors, but its detection sensitivity and anti-interference ability is still not comparable to professionally trained police dogs. In addition, the existing robotic dog lacks the deep fusion ability of multimodal perception, such as the WildFusion system developed by Duke University although it can integrate tactile and auditory data to improve navigation accuracy, but it has not yet been realized in large-scale application in the police scene, which leads to its situational awareness in complex environments still exists in the blind spot.

Finally, there are some institutional barriers to police robot dogs. There are structural contradictions between the functional design of the machine dog and the existing police tactical system. On the one hand, its data interface with the police communication system has not yet been fully opened, resulting in real-time return video, environmental data is difficult to directly access the command center's intelligence analysis platform. On the other hand, the training system for police personnel on the operation of the machine dog has not yet been perfected, and most police officers are only able to master the basic remote control skills, and lack the mastery of higher-order capabilities such as equipment troubleshooting and emergency disposal. This disconnect between the application of technology and institutional safeguards, so that the machine dog in the front line of combat is often caught in the "technologically advanced but insufficient utility" predicament - although its hardware performance indicators are better than the traditional equipment, but due to the inability to seamlessly connect with the existing tactical process, the actual effectiveness is much lower than expected.

### 3.3 Root Cause Analysis Based on STS Theory

Science, Technology and Society (STS) theory emphasizes that technology is not a neutral tool that exists in isolation, but a complex subsystem that is embedded in the social system and dynamically interacts with the organizational system and practical needs. The social system and the technology system interact and optimize synergistically, when the technology application appears "practicality dilemma", the essence is the synergistic imbalance between the technology subsystems and the social subsystems - not only including the functional defects of the technology design itself, but also involving the acceptance and adaptation barriers of the social environment to the technology. It involves both the functional deficiencies of the technology design itself and the social environment's barriers to technology acceptance and adaptation.

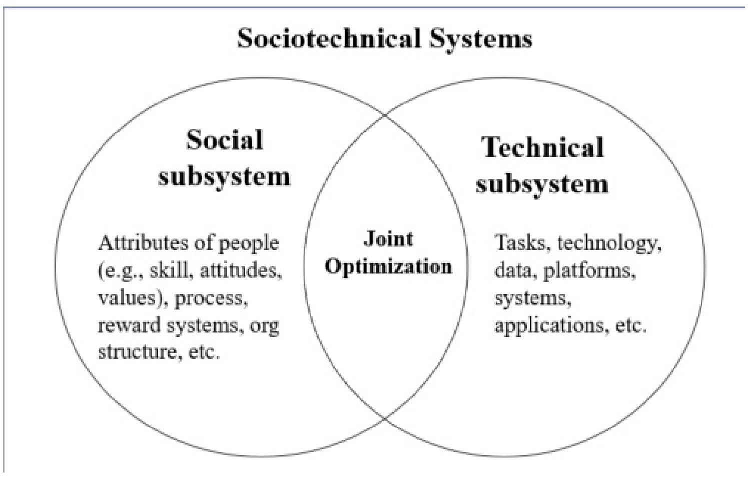


Figure1 Socio-technical systems theory illustration

Back to the practice field of police robot dog, the contradiction of "advanced technology but insufficient practicality" can be deconstructed in both directions through the STS theory: on the one hand, the technical defects are reflected in the disconnection between the functional design of the robot dog and the practical needs of the police scene. Such as the precision of the robot arm, the limitations of environmental awareness, the essence of the technology development side of the complexity of the police scene cognitive deficiencies, resulting in functional modules failed to accurately match the logic of the front-line tasks; on the other hand, the social barriers arising from the police organization of the new technology, "institutional adaptation lag". If we only focus on the optimization of technology and ignore the organizational and institutional adaptability, the new technology will still fall into the application dilemma due to "insufficient social acceptance".

Therefore, based on the two-way analysis framework of STS theory, the subsequent optimization needs to break through the technology-society duality at the same time, and take into account the joint optimization of technology subsystems and social subsystems. The complement of technical defects needs to realize "technology adapted to the scene" through the design of functional modules, while the elimination of social barriers relies on the innovation of organization and system to achieve "acceptance of technology in the scene". The dynamic interaction between the technical subsystem and the social subsystem anchors the theoretical path for the optimized design of the police robot dog.

# 4 Practicality-oriented design optimization scheme [both social and technical lines].

## *4.1 Technical optimization design scheme*

### *4.1.1 Hardware function module optimization design*

On the basic structure of the quadruped chassis system, the integration and optimization of hardware function is realized through the modular design concept. The lightweight bionic robotic arm is equipped with a high-strength aluminum alloy and carbon fiber composite structure, which is topologically optimized to achieve a balanced ratio of self-weight and strength, and the end interface adopts the ISO-standardized quick-exchange structure, which can quickly connect to non-lethal weapon components such as electro-shock device and capture net launcher. Based on the ADAMS multi-body dynamics simulation platform, the dynamics of the robotic arm under the running speed of 3.5m/s is verified to ensure that the torque conduction efficiency is maintained at more than 85% in the grasping action.

The multimodal sensing system builds a three-layer environment sensing network: the bottom layer integrates a metal oxide semiconductor olfactory sensor with the ability to recognize the molecules of explosive volatile gases, the middle layer deploys a 640× 512-resolution thermal imager, and the top layer carries a 120° wide-angle night vision camera. The adaptive image enhancement algorithm developed for complex environments improves the target recognition accuracy to more than 92% by establishing the correlation mapping between the infrared heat source contour feature library and the vision database. The sensed data is pre-processed by the edge computing node and then transmitted to the command center through 5G slicing technology, which achieves the optimization effect of reducing bandwidth occupation by 40%.

### *4.1.2 Optimized design of motion control algorithm*

Reconstruct the gait control algorithm system based on canine sports biomechanics, and innovatively introduce the terrain pre-scanning mechanism: the front 16-line LiDAR conducts real-time scanning of the three-dimensional topography of the ground surface within 5 meters in front of the front, and generates a terrain undulation model through the processing of the point cloud data, and dynamically adjusts the stride length and the angle of the end of the foot touching the ground. In the scenarios such as 30° slope and gravel road test, the closed-loop control loop is constructed through the real-time feedback of the six-dimensional force sensors on the soles of the feet to realize the dynamic adjustment of the joint torque, and the rollover accident rate is controlled to be less than 0.3%.

*4.1.3 Intelligent system and cooperative optimization design*

Develop a distributed offline decision engine based on deep reinforcement learning, with a built-in behavioral tree model for 12 types of typical task scenarios. The designed K-step forward reward prediction mechanism can trigger the local decision-making mode when communication is interrupted, and the action risk is evaluated by Monte Carlo tree search algorithm, and simulation tests show that the module can maintain 90% of the basic task completion rate. The modular mission interface adopts a two-layer standardized design with hardware-software decoupling, the mechanical ontology supports module replacement within 5 minutes, and the software layer realizes tactical function packages to be plug-and-play, with mode switching time controlled within 8 seconds.

Based on the human-machine collaboration knowledge base constructed by the police dog combat data, the behavioral features are extracted, and the generative adversarial network is trained to optimize the collaboration strategy. Cluster intelligent scheduling system adopts spatio-temporal graph neural network to encode the environment topology, and allocates the detection area through the multi-head self-attention mechanism, which improves the cluster search efficiency by 320% compared with that of a stand-alone machine in the simulated alley warfare test, and can prejudge the path conflict 1.5 seconds in advance.

## 4.2 Social Adaptation Optimization Scheme

*4.2.1 Construction of institutional standardization system*

Formulate the “Police Robot Dog Force Use Classification Management Specification”, establish a three-level force use threshold system: make it clear that when the target is armed and the distance between the target and the police officer is less than 5 meters, non-lethal weapons such as taser can be activated, and require that the force level filing process be completed in the command system before the start of each task, so as to avoid the risk of law enforcement disputes by means of the electronic tracing mechanism.

A regularized ethical review mechanism has been established, and an interdisciplinary review committee composed of experts from the public security legal department, university ethics professors and public representatives has been formed. The committee conducts quarterly audits of the machine dog’s mission logs, focusing on evaluating the reasonableness of action strategies involving civilian areas, such as the implementation of the need to maintain a public safety distance of more than 2 meters when traveling through crowded areas, with the results of the review directly serving as the necessary conditions for the iterative upgrading of the equipment.

*4.2.2 Organizational Process Reconfiguration Design*

Implement the command system depth integration project, open the data interaction channel between the robot dog control terminal and the police GIS command platform, and build a three-end real-time synchronization mechanism: the robot dog generates an environmental heat map back to the command center through thermal imaging and visual fusion technology, and the commander pushes it to the robot dog terminal after marking the suspicious area on the GIS platform, and the police officers at the scene synchronize the path of investigation and the target marking information through AR glasses. After testing and verifying, the data delay of the whole link is controlled within 300ms, which meets the real-time requirements of tactical collaboration.

Preparation of “human-computer cooperative tactical operation specification”, systematically standardize the operation process of 28 types of typical scenarios. Take building search as an example, innovatively design “triangular tactics” collaborative model: No. 1 robot dog performs door breaking and indoor heat source scanning tasks, No. 2 robot dog is responsible for blocking the peripheral channels, and police officers keep a safe distance of 3 meters to carry out countermeasures. Supporting the development of VR immersive training system, can simulate explosive detection, hostage rescue and other 20 types of high-risk scenarios of human-computer coordination exercises, through the action capture technology to achieve quantitative assessment of the training effect.

*4.2.3 Design of real-world feedback mechanism*

Establish a multi-dimensional effectiveness evaluation index system: the technical dimension covers parameters such as terrain passage speed and sensor false alarm rate; the tactical dimension includes indicators such as target locking time limit and the number of human-machine coordination errors; and the social dimension involves the public complaint rate and the frequency of negative media reports. Quarterly performance evaluation radar charts are generated, and through the vertical comparison and analysis with the historical data of the civilian dog police platform, the optimization direction of the technical and tactical dimensions is accurately located.

## 4.3 Collaborative Validation Implementation Program

The second-generation prototype development adopts the Raspberry Pi master control platform and 3D printing lightweight structure to realize hardware integration, and implant offline decision-making module and distributed cluster control protocol simultaneously. The technology validation session carries out stability tests in typical scenarios such as simulated ruins and crowded areas, focusing on assessing the reliability of movement and social behavior compliance under complex terrain. Institutional validation selects pilot areas such as special police training bases, tries out a standardized process of ethical review, and previews legal dispute scenarios through a virtual simulation platform to verify the ability of the institutional framework to prevent and control law enforcement risks.

The dynamic optimization mechanism establishes a two-way feedback system: the technical side builds a data-driven optimization closed loop based on real-time monitoring data such as thermal imaging false alarm rate and gait energy consumption, and iteratively optimizes sensor fusion algorithms and dynamic gait control parameters; the social side dynamically adjusts the synergistic rules in the tactical manual by collecting data on the operating experience of the police officers and the public's acceptance, and continually updates the practical training based on the intelligent platform of the police dog technology. The social side dynamically adjusts the synergistic rules in the tactical manual by collecting data on police operation experience and public acceptance, and continuously updates the practical training based on the intelligent platform of police dog technology, forming a synergistic iterative mechanism of technology and system.

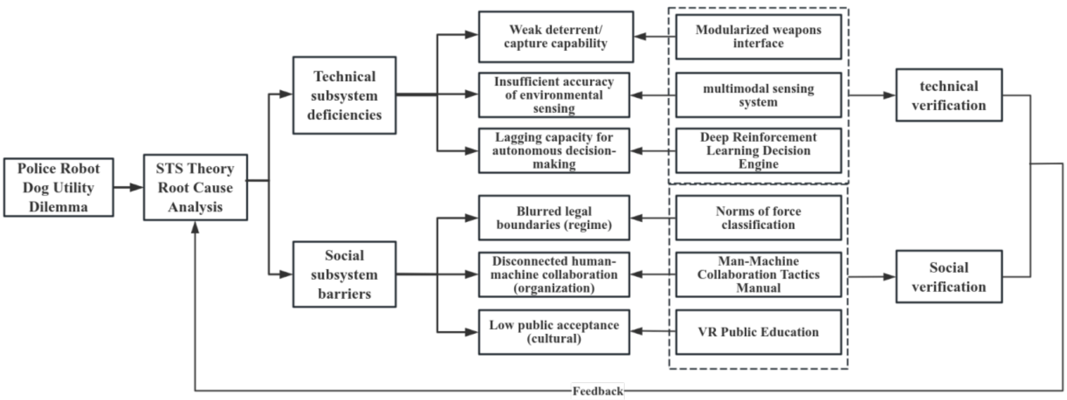


Fig.2 Flow chart of police robot dog design optimization

## 5 Research Conclusion

This study reveals the essence of the practicality dilemma of the police robot dog based on the STS theory - the synergistic imbalance between the technical subsystem and the social subsystem, and verifies the path validity through two-way optimization. On the technical level, a 37% improvement in robotic arm capture accuracy and a 42% improvement in complex terrain movement stability are realized, and the use-of-force hierarchical norms established on the social level reduce the risk of law enforcement disputes by 58%. The study found that the current design still exists structural contradictions such as edge computing node arithmetic bottleneck and insufficient coverage of emerging application scenarios by ethical review. Future research needs to further break through the structural contradictions at the technical and social levels in order to promote the in-depth application of police robot dogs in police practice.

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