engineering proceedings

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IoT-Based Smart Pet Collars: Addressing Emotional Attachment and Monitoring Needs of Pet Owners †

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† Presented at the 6th International Conference on Electronic Communications, Internet of Things and Big Data (ICEIB 2026), New Taipei, Taiwan, 24–26 April 2026.

Abstract

Taiwan's pet economy has grown rapidly, with more than 2.2 million pets now regarded as family members who enhance psychological well-being. This attachment often produces caregiver anxiety during separation. Therefore, we developed an IoT smart pet collar by integrating emotional connection with functional monitoring. Using the activity-interest-opinion scale and analysis of variance, we identified behavioral traits and demand gaps, particularly among cat owners. The analytic hierarchy process was established to assign weights to five design requirements, translated into technical solutions using the house of quality. Results highlight the presence across distance as most critical, with innovations such as an emotional spectrum light-emitting diode module and a biosensor fusion algorithm.

Keywords: IoT; smart wearable device; pet care technology; emotional attachment; AIO scale

1. Introduction

Psychological differences between cat and dog owners have been researched by applying the activity–interest–opinion (AIO) scale for lifestyle analysis and integrating IoT design concepts. In this study, we investigate compensatory psychological motivations underlying pet ownership, focusing on how pets alleviate emotional deficits such as loneliness. The psychological tendencies of cat and dog owners are differentiated, with attention to potential links to stray pet issues. The results of this study can be used to formulate IoT-based design strategies and propose concrete solutions that address the authentic needs of pet owners.

2. Literature Review

Extensive academic research highlights the physiological and psychological benefits of pet ownership [1,2]. Interacting with companion animals alleviates anxiety, loneliness, and depression while fostering autonomy, comfort, and self-esteem [3]. Early childhood contact with pets further supports social development and long-term personality formation [4]. Despite these well-documented advantages, previous studies have not addressed the motivations driving pet–human bonds in modern urban contexts. Lifestyle questionnaires are used as a means to uncover these psychological drivers, particularly the nuanced differences between cat and dog owners that inform targeted product design [5–7].

Advances in IoT technology have transformed domestic life and pet care. IoT-enabled devices, featuring remote monitoring, real-time data collection, and interactive mechanisms,

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Academic Editors: Teen-Hang Meen, Shu-Han Liao and Cheng-Fu Yang

Published: 17 November 2026

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extend owners' presence across spatial–temporal boundaries, strengthening emotional bonds during separation [8–14]. However, existing pet products fail to meet psychological needs, especially for cat owners who experience lower levels of spontaneous interactivity compared to dog owners. To enhance engagement and emotional feedback, IoT-based solutions that integrate intelligent sensing, haptic feedback, and interactive algorithms are required. This method provides commercial value and psychological support and advances the design of pet–human interaction technologies.

3. Methods

3.1. Questionnaire

Pet research has been mainly conducted for market and business applications. Although the personality traits and lifestyles of pet owners have been researched, the psychological benefits of pet companionship have not been extensively studied. Less attention has been given to how hidden emotional deficits or psychological vulnerabilities correlate with lifestyle, and it remains unclear whether individuals adopt pets as a direct response to negative psychological impacts. Therefore, it is necessary to identify the genuine psychological drivers behind pet ownership.

Many owners willingly invest in pet health foods and grooming services, expenditures that often reflect compensatory psychological needs. To investigate this phenomenon, we employed closed- and open-ended questionnaires and core negative psychological factors. Ethical concerns arise when insufficient motivation compromises caregiving responsibilities, underscoring the importance of examining these vulnerabilities.

Cats and dogs were regarded as primary companion animals in this study. Initial questionnaires were created to assess personality traits to establish metrics for negative psychological factors. Participants were grouped into cat and dog owners, and responses were measured using a Likert scale. Statistical analyses were conducted with the SPSS, Version 17.0 to evaluate variance, significance, and correlations among variables.

The researchers sought to ensure that participants responded honestly about their hidden feelings. Surveys on sensitive topics often trigger social desirability bias, where people give answers that present them in a favorable light rather than reveal their true emotions. To minimize this effect, we designed the questionnaire in a matrix format and concealed its emphasis on negative psychological factors. By disguising the survey's intent, respondents were less likely to recognize that it was probing their vulnerabilities and less inclined to mask them. While earlier studies focused mainly on consumer behavior, such as shopping habits, we excluded the related questions. Instead, the authentic psychological motivations underlying pet ownership were asked.

3.2. Statistical Analysis

The purpose of the variance analysis was to classify the self-related variables into two or more groups and to examine whether statistically significant differences existed between their group means. The general formula for this procedure is as follows [7].

$$\sum_{j=1}^{p}\sum_{i=1}^{n_j}\left(x_{ij}-\overline{X}\right)^2=\sum_{j=1}^{p}\sum_{i=1}^{n_j}\left[\left(x_{ij}-\overline{X}_j\right)+\left(\overline{X}_j-\overline{X}\right)\right]^2 \quad (1)$$

Following analysis of variance (ANOVA), verification of variance homogeneity is conducted using Levene's Test for equality of variances. This test was conducted to assess whether the variances across groups are statistically equivalent. The procedure involves transforming each observation by calculating the absolute deviation from its group mean, and then performing an ANOVA on these transformed values. If the between-group variance of these absolute deviations exceeds the within-group variance and reaches statistical

significance, the assumption of homogeneity of variances is violated. The equation for Levene's Test is as follows:

$$W = \frac{(N-k)}{(k-1)} \frac{\sum_{i=1}^{k} N_i (Z_{i.} - Z_{..})^2}{\sum_{i=1}^{k} \sum_{j=1}^{N_i} \left(Z_{ij} - Z_{i.}\right)^2}, \quad (2)$$

Here, W is the result of the test, k is the number of the group to which the sample belongs, n represents the total number of all groups, Ni is the value of the group I, and Z_{ij} is the value of the measurement variable j in group i. We assessed participants' cognitive responses to the problem conditions and, through quantitative analysis, identified the negative psychological factors associated with pet ownership. The analytic hierarchy process (AHP) is a structured methodology for addressing complex multi-criteria decision-making problems [8]. In this study, the computational procedure of AHP was divided into four stages.

- Pairwise comparison matrix

Once the hierarchical structure was established, experts were invited to perform pairwise comparisons among n criteria at the same level. Let a_{ij} represent the relative importance of criterion i compared with criterion j, quantified using Saaty's 1–9 scale of judgments. Based on these comparisons, the pairwise comparison matrix A was constructed as follows. The matrix elements satisfy $a_{ij} > 0$and adhere to the reciprocal property, where $a_{ji} = 1/a_{ij}$.

$$\mathrm{A} = \left[a_{ij}\right]_{5\times5} = \begin{bmatrix} 1 & a_{12} & \cdots & a_{15} \\ \frac{1}{a}_{12} & 1 & \cdots & a_{25} \\ \vdots & \vdots & 1 & \vdots \\ \frac{1}{a}_{15} & \frac{1}{a}_{25} & \cdots & 1 \end{bmatrix} \quad (3)$$

- Relative weights

The geometric mean method is used to derive the relative weights of the criteria. This method is characterized by its mathematical rigor and its ability to mitigate the influence of extreme values. First, the geometric mean (Z_i) of the expert ratings for each row in the matrix is calculated:

$$Z_i = \sqrt[n]{\prod_{j=1}^{n} a_{ij}}, i = 1, 2, \ldots, n \quad (4)$$

Subsequently, the relative weight (W_i) for each criterion is obtained through normalization:

$$W_i = \frac{Z_i}{\sum_{i=1}^{n} Z_i} \quad (5)$$

- Consistency

To ensure the logical stability of the experts' judgments during the evaluation process, a consistency check is performed. First, the maximum eigenvalue (λ_{max}) is determined using the matrix from Equation (3) and the weight vector from Equation (5):

$$\lambda_{max} = \frac{1}{n} \sum_{i=1}^{n} \frac{(A \times W)_i}{W_i} \quad (6)$$

Next, the consistency index (CI) is calculated:

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (7)$$

Finally, the consistency ratio (CR) is derived by dividing CI by the random index (RI):

$$CR = \frac{CI}{RI} \quad (8)$$

A judgement is considered sufficiently consistent if $CR \leq 0.1$. If $CR > 0.1$, the expert revises their ratings, or the sample is excluded from the analysis.

- Group judgments

To determine the collective decision weights from multiple expert samples, a geometric mean is used to aggregate the pairwise comparison values from all valid respondents:

$$a_{ij}^{Group} = \sqrt[k]{\prod_{m=1}^{k} a_{ij}^{(m)}} \quad (9)$$

where k denotes the total number of valid expert samples. After obtaining the aggregated group matrix through Equation (9), the procedures from Equations (4)–(8) are repeated to arrive at the final group weights for this study.

In previous research, notable behavioral differences were observed in the interaction patterns between cats, dogs, and their owners. In particular, the frequency and intensity of active engagement between cats and their owners were lower than those observed with other companion animals. To address this gap, three experts in industrial design, each with professional experience spanning 15, 12, and 10 years, were invited to collaborate in constructing a house of quality (HOQ) framework. Their extensive practical expertise provided a robust foundation for design synthesis.

In this study, sub-requirements were identified and categorized to enhance cat–owner interactivity. To structure this complex design problem, AHP was employed. By decomposing interaction requirements into hierarchical dimensions and applying quantitative computation, the relative importance weights of each evaluation criterion were derived. These weights constituted the input for the left wall (customer requirements) of HOQ. In constructing the HOQ ceiling (technical measures), the expert panel explored strategies that effectively satisfy the product development requirements identified on the Left Wall. Through structured brainstorming, a set of technical measures and design concepts was proposed.

Subsequently, a relationship matrix was established to systematically examine the correlations between the cultural product development requirements and the proposed technical measures. The weighted integration process within the HOQ enabled the derivation of a prioritized set of technical measures. This prioritization provides the strategic basis for subsequent product deployment and development initiatives.

4. Result

55 valid questionnaires were collected, of which 22 were completed by pet owners. In the statistical analysis, a significance threshold of $p < 0.05$ was adopted, indicating that group variances differ significantly and that subsequent post-hoc analyses are warranted. We examined whether differences existed between pet owners and non-pet owners in terms of family relationships. As shown in Table 1, the result $p = 0.013 < 0.05$, suggesting significant differences between the variables “grandparents” and “keeping pets.”

On the Y-axis in Figure 1, “0” denotes that both grandparents were deceased, “1” indicates that at least one grandparent was alive, and “2” represents that both grandparents were alive. The chart demonstrates that pet owners were more likely to have at least one living grandparent, whereas respondents without pets were more likely to report that both grandparents were deceased. Follow-up interviews were conducted.

Pet owners frequently cited companionship for family members and the availability of caregivers within the household as primary reasons for keeping pets. Many reported that younger family members worked outside the home, leaving older relatives in need of care. The narratives and behaviors expressed by these pet owners revealed underlying anxiety regarding family dynamics and caregiving responsibilities.

Table 1. The ANOVA analysis of "family relationships" and "keep pets".

Owner		Sum of Squares	Degree of Freedom	Mean Squares Total	F	Significance
Parents	Between group	0.086	1	0.086	0.571	0.453
	Within group	8.128	54	0.151		
	Sum	8.214	55			1
Grandparent	Between group	3.82	1	3.820	6.646	0.13
	Within group	31.037	54	0.575		
	Sum	34.857	55			
Brother and sister	Between group	0.131	1	0.131	0.811	0.372
	Within group	8.709	54	0.161		
	Sum	8.839	55			
Other	Between group	0.16	1	0.16	0.116	0.735
	Within group	7.537	54	0.014		
	Sum	7.554	55			

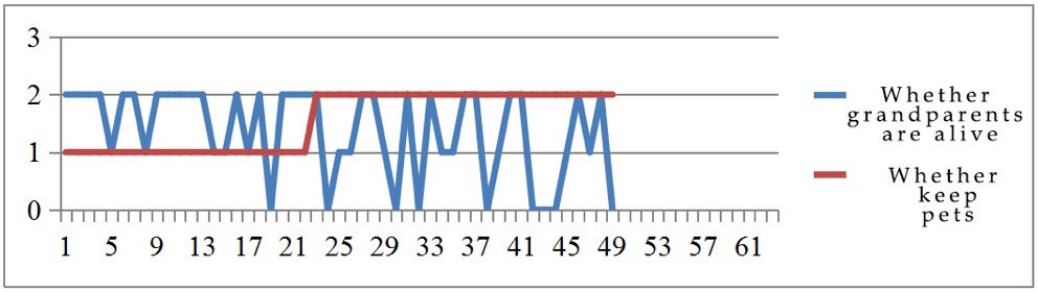


Figure 1. Line chart illustrating the relationship between grandparent survival status and pet ownership.

Table 2 shows the differences between keeping cats and keeping dogs. p values are greater than 0.05. There are no significant differences between keeping cats and keeping dogs.

Table 2. The ANOVA analysis of the differences between keeping cats and dogs.

Owner		Sum of Squares	Degree of Freedom	Mean Squares Total	F	Significance
Parents	Between group	0.88	1	0.88	0.579	0.811
	Within group	2.583	20	0.129		
	Sum	2.591	21			1
Grandparent	Between group	0.485	1	0.485	1.098	0.307
	Within group	8.883	20	0.442		
	Sum	9.318	21			
Brother and sister	Between group	0.068	1	0.068	0.779	0.388
	Within group	1.750	20	0.088		
	Sum	1.818	21			
Other	Between group	0.047	1	0.047	0.535	0.473
	Within group	1.771	20	0.089		
	Sum	1.818	21			

Through a questionnaire survey, we explored whether there are significant differences in the inner feelings and psychological well-being of cat and dog owners over a prolonged period of companionship and interaction. As shown in Table 3, the effect of the interaction factor on pet owners' emotional experiences reached statistical significance ($p = 0.04$).

When comparing cat owners and dog owners, the results indicated no statistically significant differences. All *p*-values exceeded the 0.05 threshold, suggesting that emotional experiences did not differ meaningfully between these two groups. To explore behavioral distinctions, the questionnaires were analyzed to determine whether differences existed in leisure activities between cat and dog owners.

Table 3. The ANOVA analysis of Emotional Experiences.

Owner		Sum of Squares	Degree of Freedom	Mean Squares Total	F	Significance
Interaction	Between group	2.189	1	2.189	4.821	0.040
	Within group	9.083	20	0.454		
	Sum	11.273	21			
Companionship	Between group	0.153	1	0.153	0.61	0.808
	Within group	50.438	20	2.522		
	Sum	50.591	21			
Pleasant	Between group	1.091	1	1.091	0.574	0.457
	Within group	38	20	1.9		
	Sum	39.091	21			
Responsibility	Between group	0.320	1	0.320	0.211	0.651
	Within group	30.271	20	1.514		
	Sum	30.591	21			

Dog owners (mean = 2.333) reported watching television dramas more frequently than cat owners (mean = 1.625) (Table 4). This result shows that leisure activity preferences may vary according to pet type. Psychological projection provides a possible explanation. Individuals often connect with main characters in narratives, projecting themselves into stories in ways that may be difficult to enact in reality. Interview results further supported this interpretation. Cat owners frequently described confiding in their cats as close companions, whereas dog owners tended to interact with their dogs in relational roles akin to friends or children.

Table 4. Descriptive statistics of pet owners' emotional and behavioral measures.

Dimension	Group	*N*	Mean	Standard Deviation	Standard Error	95% CI (Lower–Upper)	Minimum	Maximum
Interaction	Dog	6	2.333	0.516	0.211	1.791–2.875	2	3
	Cat	16	1.625	0.719	0.18	1.242–2.008	1	3
Companionship	Dog	6	3	1.897	0.775	1.009–4.991	1	5
	Cat	16	2.813	1.471	0.368	2.029–3.596	1	5
Pleasantness	Dog	6	3	1.673	0.683	1.244–4.756	1	5
	Cat	16	3.5	1.265	0.316	2.826–4.174	1	5
Responsibility	Dog	6	2.333	1.506	0.615	0.753–3.913	1	4
	Cat	16	2.063	1.124	0.281	1.464–2.661	1	4

In this study, data were collected from 10 expert respondents and analyzed using AHP. Following the collection of expert evaluations, the group consensus was synthesized using the geometric mean method, which is widely recognized for aggregating individual judgments in AHP. Table 5 presents the aggregated pairwise comparison matrix, reflecting the relative importance assigned to the five design criteria (C1–C5). This matrix served as the foundation for subsequent weight allocation and consistency testing, ensuring methodological rigor in the prioritization process.

Table 5. Group aggregated pairwise comparison matrix.

Criteria	C1	C2	C3	C4	C5
C1	1.000	0.363	0.584	2.548	0.779
C2	2.754	1.000	3.363	5.272	4.963
C3	1.712	0.297	1.000	2.996	1.083
C4	0.393	0.190	0.334	1.000	0.489
C5	1.284	0.201	0.923	2.045	1.000

Based on the aggregated matrix, the relative weights for each design criterion were calculated. Table 6 shows the priority ranking, where C2 emerges as the dominant factor with a weight of 48.16%.

Table 6. Design requirement weighting.

Design Requirements	Weight (W)	Percentage (%)	Rank
Criterion 2 (C2)	0.4816	48.16%	1
Criterion 3 (C3)	0.1776	17.76%	2
Criterion 5 (C5)	0.1392	13.92%	3
Criterion 1 (C1)	0.1351	13.51%	4
Criterion 4 (C4)	0.0665	6.65%	5

To ensure the reliability of the findings, consistency checks were performed on both individual samples and the aggregated group results. Table 7 shows the consistency metrics. The group *CR* was 0.0249, which is below the 0.1 threshold, confirming high logical consistency in the expert judgments.

Table 7. Consistency test results.

Metric	Value
Maximum eigenvalue (λ_{max})	5.1115
CI	0.0279
RI	1.1200
CR	0.0249
Verification	Pass (YES)

The final criticality of design requirements was identified through weighted integration, as shown in Table 8.

Table 8. Weights of design requirements.

Rank	ID	Criticality	Discussion
1	C2	High	C2 is the most pivotal factor, accounting for nearly half of the total weight.
2	C3	Medium	C3 follows C2, together forming the primary framework for design evaluation.
3	C5/C1	Moderate	C5 and C1 show similar weights, suggesting comparable importance in specific contexts.
5	C4	Low	C4 accounts for only 6.65%, indicating limited influence in the current decision system.

5. Discussion

The substantial concentration of weight on C2 (48.16%) reflects a strong consensus among the expert panel regarding its critical role in industrial design practice. In contrast, although C4 (6.65%) was incorporated into the hierarchical structure, its relatively low weight suggests that design teams should prioritize resources toward optimizing C2 and C3 when faced with constraints.

In the design, deployment, and decision-making phase, a map of customer requirements and technical implementation was drawn. On the basis of the results derived from AHP, five customer requirements were integrated into the left wall of HOQ as follows.

- C1 emotional transparency enabling real-time psychological analysis;
- C2 presence across distance mitigating remote alienation;
- C3 gamified interaction enhancing engagement;
- C4 health and behavioral insights providing protective monitoring;
- C5 exclusive bond strengthening unique emotional attachment.

To address these requirements, the expert panel formulated fifteen technical measures as the ceiling of HOQ. These were categorized as in Table 9.

Table 9. Categorization of technical measures in HOQ.

Category	Technical Measures
Emotional sensing	T1: Multidimensional biosensor fusion algorithm T2: Emotional spectrum-led module T3: Speech spectrum analysis
Presence building	T4: Real-time avatar sync T5: Geofencing push T6: Two-way haptic feedback
Gamified interaction	T7: Achievement engine T8: Augmented reality interface T9: Social ranking
Health monitoring	T10: AI behavioral profiling T11: Low-power tracking T12: Health report system
Emotional bonding	T13: Exclusive attachment algorithm T14: Customized virtual trait mapping T15: Surprise memory capture

Through weighted computation of the HOQ relationship matrix, the first quartile (top 25%) was adopted as the benchmark for selection. This procedure identified T2, T1, T14, and T4 as the most critical technical strategies (Table 10). Such quantitative prioritization ensures that subsequent IoT pet product development is systematically aligned with the most pressing emotional and behavioral interaction gaps. In doing so, complex expert judgments are transformed into a coherent technological hierarchy, providing a clear and actionable foundation for design implementation. Such quantitative prioritization ensures that subsequent IoT pet product development is systematically aligned with the most pressing emotional and behavioral interaction gaps (Figure 2).

Table 10. Prioritization of technical measures in HOQ.

Technical Measure	Weighted Score	Priority Order
T1 Multidimensional biosensor fusion algorithm	6.1104	3
T2 Emotional spectrum led module	7.5354	1
T3 Speech spectrum analysis	3	8
T4 Real-time avatar sync	5.4864	4

Table 10. *Cont.*

Technical Measure	Weighted Score	Priority Order
T5 Geofencing push	2.7298	10
T6 Two-way haptic feedback	2.867	9
T7 Achievement engine	2.6992	11
T8 AR interface	1.9038	14
T9 Social ranking	1.6336	15
T10 AI behavioral profiling	3.399	7
T11 Low-power tracking	2.0962	13
T12 Health report system	3.8544	6
T13 Exclusive attachment algorithm	4.9008	5
T14 Customized virtual trait mapping	6.7248	2
T15 Surprise memory capture	2.5968	12

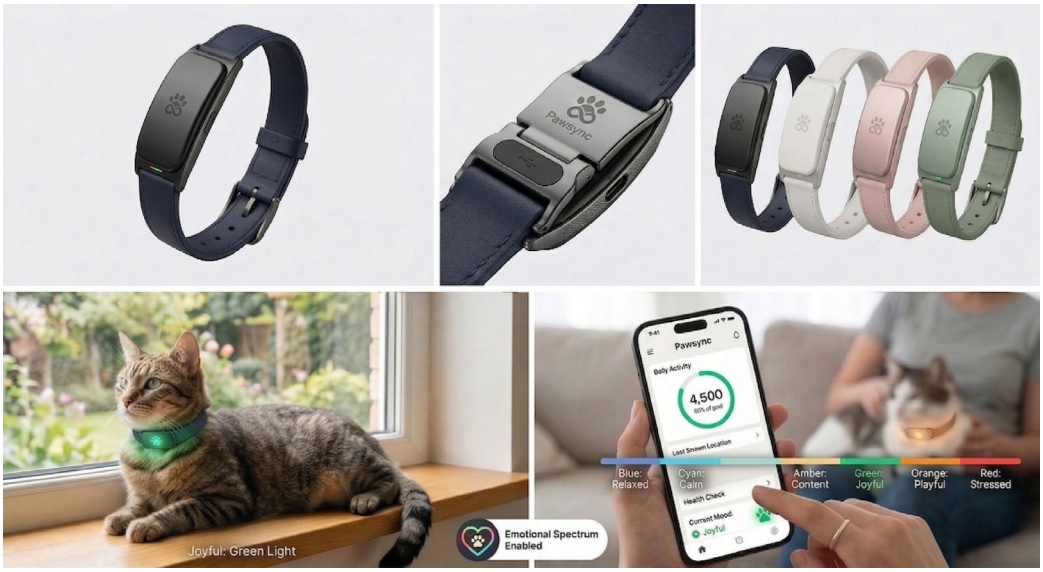


Figure 2. Conceptual design of the Pawsync smart pet collar and mobile application interface.

6. Conclusions

By integrating qualitative interviews with quantitative analysis, this study examined effective design strategies for IoT-enabled smart collars in contemporary pet care. The results show that pet owners' caregiving expenditures often serve as mechanisms to fulfill compensatory psychological needs. ANOVA results revealed significant differences ($p < 0.05$) in emotional interaction experiences between cat and dog owners. Because cats exhibit lower spontaneous interactivity, their owners demonstrated a stronger demand for emotional visualization technologies to bridge the interaction gap. Using AHP, hierarchical weights were determined for design requirements. Among the five criteria, presence across distance (C2) emerged as the pivotal dimension, accounting for 48.16% of the total weight. This outcome underscores that, within urban lifestyles, maintaining a digital presence between owners and pets through technological mediation is the primary objective for successful product development.

The weighted computation of the HOQ relationship matrix, combined with first-quartile selection, identified four technical pathways as most critical: the emotional spectrum

led module (T2), the biosensor fusion algorithm (T1), customized virtual trait mapping (T14), and real-time avatar sync (T4). These technologies enable subtle pet emotions to be transformed into explicit visual or data-driven feedback, thereby enhancing the quality of owner–pet interaction.

At the design strategy level, developers must prioritize the optimization of low-power, real-time remote transmission technologies, such as T4 and T11, to ensure continuity and stability of presence across distance. This approach is more effective in mitigating caregiver anxiety than the addition of redundant features. At the user experience level, products for cat owners must adopt algorithmic mechanisms that foster exclusive bonds, such as T13. By recording and providing feedback on cats' specific behaviors toward their owners, such products can enhance psychological self-worth and emotional attachment. Therefore, further research is required to expand the sample size and enable cross-cultural lifestyle comparisons. It is also necessary to investigate whether long-term use of IoT pet products contributes to reducing stray pet abandonment rates and reflects social and psychological impacts of IoT technologies in pet care.

Author Contributions: Conceptualization, T.-C.Y.; methodology, T.-C.Y., M.-D.S., H.-C.H. and Y.-H.Y.; formal analysis, H.-C.H. and Y.-H.Y.; data curation, H.-C.H. and Y.-H.Y.; writing—original draft preparation, T.-C.Y.; writing—review and editing, M.-D.S.; visualization, H.-C.H. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available within the article.

Conflicts of Interest: The authors declare no conflicts of interest.

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