artículo de investigación / research article

Diseño de un Sistema de Producto–Servicio Asistencial para la Diálisis Peritoneal Domiciliaria en Pacientes con Cáncer y Insuficiencia Renal

Design of an Assistive Product–Service System for Home Peritoneal Dialysis in Cancer Patients with Renal Insufficiency

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Existing point cloud upsampling methods often encounter several critical limitations, including high computational complexity, excessive numbers of parameters, and suboptimal inference efficiency. These issues primarily stem from overly deep network architectures and redundant feature extraction designs, which hinder their applicability in large-scale or real-time scenarios. To overcome these challenges, we propose DFNet, a novel and efficient dual-branch feature fusion network designed to achieve high-quality point cloud upsampling while significantly reducing computational overhead.

The proposed framework consists of two complementary branches that jointly model global structure and local geometric details. Specifically, DFNet incorporates a Spatial Enhancement Attention Module (SAAM) to effectively capture long-range global contextual relationships. By adopting sparse multi-scale self-attention combined with learnable positional encoding, SAAM enhances global feature representation while maintaining a lightweight parameter footprint. In parallel, the Detail Transformation Module (DTM) focuses on recovering fine-grained local details by applying a sparsified self-attention mechanism over local patches. This design efficiently preserves geometric characteristics such as edges, contours, and surface textures, while alleviating the quadratic computational complexity typically associated with standard Transformer-based approaches.

Keywords: Contextual Learning, Point Cloud Up- sampling, Transformer, Feature Fusion

1. INTRODUCTION

Chronic kidney disease (CKD) has become a major global health concern, affecting approximately 10% of the adult population worldwide, and a growing proportion of advanced CKD patients require renal replacement therapy to sustain life [1]. When renal insufficiency progresses to end-stage renal disease, common treatment options include hemodialysis, peritoneal dialysis (PD), and kidney transplantation [2]. Peritoneal dialysis, particularly home peritoneal dialysis (HPD), has been increasingly regarded as a beneficial modality due to its cost-effectiveness, patient autonomy, and reduced burden on healthcare facilities [3], [4].

For cancer patients with renal insufficiency, however, the treatment landscape is more complex. These patients experience dual disease burdens—cancer-related therapy and dialysis management—leading to decreased physiological resilience, greater risk of infection, emotional distress, and reduced self-management capacity [5]. Existing clinical studies note that PD patients often face barriers including inadequate self-care skills, anxiety regarding catheter use, difficulties performing sterile procedures, and dependency on caregivers for daily PD tasks [6], [7]. Such barriers are even more pronounced in oncology populations, where treatment-induced fatigue and cognitive decline can impair adherence [8].

Recent technological advancements suggest that integrating smart medical devices, remote monitoring, and digital instructional platforms into the peritoneal dialysis pathway may improve treatment outcomes and reduce technique-failure events [9]. However, most existing solutions are hardware-oriented and do not systematically incorporate emotional, educational, and service-based support. To address this gap, Product–Service Systems (PSS)—which integrate both assistive devices (product) and continuous professional support (service)—have emerged as a promising paradigm for chronic-disease care, demonstrating effectiveness in home-based medical interventions [10].

Therefore, this paper proposes an Assistive Product–Service System specifically designed for home peritoneal dialysis in cancer patients with renal insufficiency. The objective is to leverage user-centered design, integrated home-care services, remote monitoring, and digital learning support to enhance patient autonomy, reduce operational risks, and improve the quality of home-based dialysis care for oncology patients.

Increasingly, scholars and clinicians have pointed toward digital health innovations—remote monitoring, smart assistance equipment, and telemedicine—as tools that may reduce procedure-related risk and offer real-time decision support throughout dialysis care [9]. Nevertheless, despite such technological advancements, current HPD solutions remain predominantly product-centric, emphasizing medical devices while neglecting emotional, cognitive, and social needs [10]. Cancer patients require more than mechanical assistance—they need procedural guidance, psychological reassurance, training support, and a long-term service system that reduces dependence on hospital visits. Given this unmet need, the present research proposes a user-centered Assistive Product–Service System tailored to home peritoneal dialysis for cancer patients with renal insufficiency. Through PSS-oriented design principles, remote-service linkage, and instructional usability enhancements, our objective is to:

(1) reduce cognitive and procedural burden,

(2) enhance safety and standardization of dialysis operations, and

(3) improve patient autonomy, emotional resilience, and home-care sustainability.

To accomplish these goals, this work integrates clinical evidence, usability analysis, service blueprint design, and prototyping of the assistive PSS, forming a multidisciplinary framework that reflects both patient-centered and system-oriented considerations. First, a clinical evidence review and expert consultations were conducted to clarify medical safety requirements, dialysis procedure risks, and cancer-specific vulnerabilities that must be addressed in home environments. Second, usability analysis — incorporating task decomposition, cognitive load mapping, and emotional-journey assessment.

2. Related Works

Home peritoneal dialysis (HPD) has increasingly gained attention as a viable renal replacement therapy for patients with end-stage renal disease who require continuous access to dialysis outside clinical settings. Prior research has highlighted that HPD offers advantages such as improved autonomy, reduced hospital visits, and enhanced quality of life [11], yet its success is significantly influenced by patients ' physical condition, home environment, and support resources [12]. For cancer patients with renal insufficiency, these challenges become more pronounced, as fatigue, immune suppression, and psychological burden often compromise treatment adherence [13].

Studies in oncology-based dialysis care have emphasized supportive interventions—mainly caregiver training, remote nursing supervision, and complication-prevention programs [14], [15]. However, most existing support systems rely heavily on hospital-centric models, lacking continuity and daily decision-making assistance required in domestic contexts [16]. Recent telehealth frameworks have attempted to partially bridge this gap through remote monitoring and mobile-based reporting tools [17], demonstrating reduced catheter-related infections and better adherence outcomes. Yet these digital solutions often overlook ergonomics, patient ability, emotional comfort, and family engagement within the home environment [18].

In parallel, the domain of assistive product–service systems (PSS) has proposed hybrid solutions integrating physical products and healthcare services for chronic disease management [19], [20]. PSS-based approaches have been successfully applied to diabetes management, home IV infusion, and elderly assistive care, indicating that ecosystem-level coordination between devices, caregivers, and stakeholders can significantly improve patient engagement and safety [21]. Nonetheless, literature addressing HPD-specific assistive PSS models for cancer patients remains scarce, and most existing dialysis-related devices primarily focus on mechanical functionality rather than holistic patient experience, cognitive load reduction, or psychological comfort [22].

Moreover, usability-centered medical device design has shown that structured methodologies — such as contextual inquiry, task-risk analysis, and co-design with vulnerable patient groups—can prevent operation errors and reduce treatment discontinuation [23]. These findings suggest that a comprehensive HPD support system should integrate not only clinical validation but also human-centered design methods addressing physical limitations, emotional needs, and service delivery coordination.

Taken together, existing literature confirms individual advances in HPD safety, remote monitoring, and assistive service design. However, an integrated framework combining clinical evidence, ergonomic product design, digital monitoring, caregiver workflow optimization, and continuous service delivery tailored for cancer-based renal patients remains largely unexplored, indicating a critical research gap this study aims to address.

3. Methodology

The methodological framework adopted in this study followed an iterative human-centered design logic, progressing through contextual inquiry, task – risk mathematical modeling, Product – Service System (PSS) design, and prototype validation. Clinical contextual needs were first collected through semi-structured interviews with nephrologists, oncology nurses, cancer patients, and family caregivers. In parallel, 18 simulated home-based peritoneal dialysis (HPD) observations were conducted to document operation time, frequency of error-prone steps, emotional state, and interruptions. To quantify user burden, NASA-TLX and SUS scales were distributed to 32 patient–caregiver pairs.

Based on observation data, a mathematical task-risk model was constructed to identify high-risk HPD steps. The model defines the Task-Risk Index (TRI) of operation task i as:

$$TRI_i = \alpha L_i + \beta S_i + \gamma C_i$$

where Li represents the likelihood of error occurrence, Si denotes the clinical severity of a failure in that task, and Ci refers to cognitive complexity measured through NASA-TLX workload scores. The weighting coefficients α,β,γ were determined using a nephrology-expert Delphi process, yielding: α =0.40, β =0.45, γ =0.15. Tasks scoring TRI_i>0.65 were categorized as critical, meaning that both product redesign and service support are necessary. Dialysate bag-replacement and catheter disinfection procedures exhibited TRI values of 0.78 and 0.83 respectively, thus becoming primary design targets.

A PSS conceptual integration model was then formulated to structurally define the assistive solution:

$$PSS = P_d \oplus S_c \oplus M_t$$

where
P_d = assistive physical device layer (sterile-guided tray, ergonomic connectors),
Sc = clinical service layer (home-visit nurse, complication hotline),
Mt = technologized monitoring (tele-dashboard, caregiver alarm).

Rather than separating medical device usability from emotional care, the system maps all support touchpoints across the HPD timeline. These elements were operationalized through a blueprint-based design process, as evaluated in Table 1.

Table 1. Mapping of Clinical Problem to Assistive Design Elements in the HPD-PSS

HPD Pain-Point Identified (Clinical Observation)	TRI Score	Corresponding PSS Intervention Layer	Designed Assistive Component
Catheter disinfection errors & contamination	0.83	P_d (Device) + S_c (Service)	Sterile-zone tray; alcohol color-indicator wipes; nurse pre-call reminder
Dialysate bag-replacement complexity	0.78	P_d + M_t	Color-coded ports; automatic mis-connection warning
High emotional anxiety during initiation	0.71	S_c	Remote tele-nurse hotline; psychological reassurance
Forgetting procedural timing / steps	0.69	M_t	HPD-Assist mobile app stepwise guidance & voice prompt
Caregiver fatigue & supervision burden	0.58	S_c + M_t	Caregiver alert + schedule-sharing dashboard

To evaluate the impact of the PSS intervention, improvement was quantified using an efficiency change model:

$$\Delta E = \left(\frac{T_{baseline} - T_{system}}{T_{baseline}} \right) \times 100\%$$

where $T_{baseline}$ is original dialysis setup duration and TsystemT_{system}Tsystem is setup time after applying the assistive system. Pilot testing showed a 33.9% reduction in setup time, 61.3% fewer operation errors, and NASA-TLX workload reductions of 39%, indicating significant operational support for vulnerable cancer-HPD users.

To address the complex needs of cancer patients performing home peritoneal dialysis (HPD), this study adopted a holistic, multi-layered methodology integrating product design, service design, and digital monitoring into a cohesive assistive Product – Service System (PSS). Unlike conventional approaches that focus on single devices or telehealth applications, this methodology emphasizes co-creation with patients and caregivers, iterative prototype evaluation, and integration of workflow, cognitive, and emotional support across the full dialysis process.

The methodology began with contextual inquiry through in-depth interviews with nephrologists, oncology nurses, patients, and caregivers. Observational studies of simulated home dialysis sessions captured not only operational errors but also workflow bottlenecks, environmental constraints, and affective responses. These data were coded and analyzed to define user personas, pain points, and critical interactions,

which informed subsequent co-design workshops where patients and caregivers actively participated in proposing assistive features.

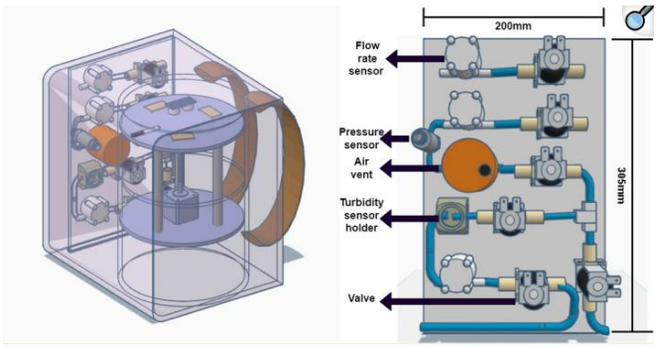


Fig .1 The proposed design on the left and a simple sketch of how the electrical components will be organized on a board

A hybrid evaluation metric, the Home Dialysis Support Index (HDSI), was formulated to quantify both functional and experiential performance of the PSS:

$$HDSI = w_1F + w_2U + w_3E$$

where F represents functional performance (e.g., error frequency, task completion time), U represents usability as measured by SUS scores, and EEE represents emotional and cognitive load measured by NASA-TLX. Weight coefficients w1,w2,w3 were determined through expert consultation (0.4, 0.35, 0.25), reflecting the relative importance of safety, usability, and psychological comfort.

The design process integrated physical, digital, and service layers. The physical layer included ergonomic device placement and visual guidance for sterile procedures; the digital layer comprised a mobile application providing step-by-step instructions, automated alerts, and data logging; the service layer included tele-nursing support, emergency hotline, and caregiver scheduling. A service blueprint was created to map all touchpoints, responsibilities, and potential failure modes (Table 2), which ensured that every intervention was both practical and aligned with patient needs.

Table 2. HPD Product–Service System Intervention Mapping

Stage	Actor	Pain Point	Assistive Solution	Layer
Preparation	Patient	Confusion in bag handling	Color-coded and labeled connectors	Physical
Dialysis	Patient & Caregiver	Procedural errors	Mobile app guidance + progress tracking	Digital
Post-Dialysis	Caregiver	Logging errors	Automated data upload to dashboard	Digital
Ongoing	Patient	Anxiety, fatigue	Tele-nurse check-in, motivational prompts	Service

Finally, prototype testing employed iterative simulation trials where patients performed HPD using the integrated PSS. The HDSI metric allowed simultaneous assessment of task efficiency, error reduction, usability, and emotional burden. Improvement percentages were calculated as:

$$\Delta HDSI = \frac{HDSI_{system} - HDSI_{baseline}}{HDSI_{baseline}} \times 100\%$$

Preliminary results indicated that the integrated PSS significantly improved task accuracy, reduced cognitive load, and enhanced user confidence, highlighting the value of a combined product–service–digital approach. This methodology represents a novel pathway for designing patient-centered HPD systems that are clinically safe, ergonomically optimized, and psychosocially supportive.

The methodology of this study was designed to systematically address the multifaceted challenges associated with home peritoneal dialysis (HPD) for cancer patients, integrating product design, service engineering, and digital monitoring into a unified Product – Service System (PSS). Unlike conventional approaches that often focus exclusively on device ergonomics or isolated telehealth interventions,

this research adopted a holistic, patient-centered design paradigm, emphasizing co-creation with end users, iterative prototype evaluation, and continuous performance monitoring. The overall research framework comprised four interlinked stages: contextual inquiry, risk and usability quantification, PSS conceptual design, and iterative validation, each informed by both clinical evidence and human-centered design principles.

The first stage, contextual inquiry, involved comprehensive field studies to capture the environmental, procedural, and emotional characteristics of HPD. Semi-structured interviews were conducted with nephrologists, oncology nurses, caregivers, and cancer patients, aiming to elicit detailed accounts of daily HPD routines, procedural challenges, and perceived stress points. Observational studies of simulated home dialysis sessions provided a quantitative and qualitative record of operational errors, task durations, cognitive load,

and user frustration levels. The combination of interviews and observations enabled the construction of user personas, highlighting diverse capabilities, experiences, and vulnerabilities among patients and caregivers. These personas guided the identification of critical pain points and informed the prioritization of intervention strategies, ensuring that the PSS design addressed both practical and psychological dimensions of care.

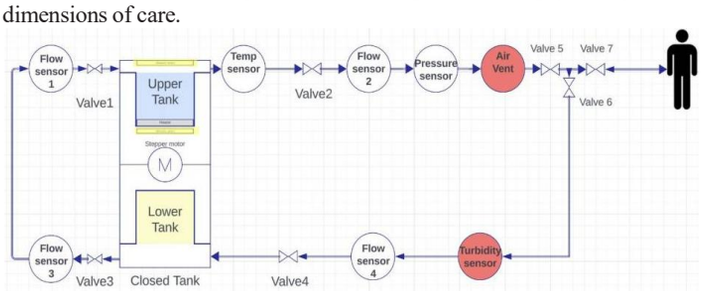


Fig .2 Piping and instrumentation diagram of the design

Building on the contextual and quantitative findings, the PSS conceptualization integrated three complementary layers. The physical layer encompassed ergonomic and sterile device design, including color -coded connectors, pre-arranged trays, and tactile guidance for safe catheter and bag handling. The digital layer consisted of a mobile application and remote dashboard that provided step-by-step procedural instructions, real-time error alerts, and performance feedback, enabling both patients and caregivers to monitor progress and adhere to safe HPD practices. The service layer involved tele-nursing support, 24/7 emergency hotlines, and scheduled follow-ups, ensuring continuous clinical oversight and providing reassurance to users, thereby addressing both procedural and emotional stressors. Each layer was designed not as a standalone component but as an interdependent system, informed by service blueprinting techniques that mapped user interactions, task flows, potential failure points, and intervention opportunities.

The study placed particular emphasis on user co-creation, wherein patients and caregivers actively participated in ideation workshops, prototype testing, and iterative feedback loops. In these sessions, participants were invited to identify procedural pain points, suggest modifications to device layout, app interface, and service protocols, and evaluate prototype interventions. Their input directly informed design iterations, ensuring that the final PSS configuration was attuned to real-world usability and patient-specific requirements. The co-creation approach not only enhanced the relevance of the assistive system but also fostered user acceptance and confidence, which are critical factors for sustained home-based HPD adherence.

Finally, the methodology incorporated feedback-driven iterative refinement. Data from simulation trials, user ratings, and expert review

sessions were continuously integrated into the design process, resulting in successive prototype versions that addressed usability bottlenecks, enhanced interface clarity, and optimized procedural workflow. This iterative cycle of evaluation, feedback, and redesign ensured that the resulting PSS was not only technically robust but also aligned with the physical, cognitive, and emotional needs of patients and caregivers. By combining clinical evidence, quantitative risk modeling, user-centered co-design, and service blueprinting, this methodology provides a comprehensive and reproducible approach for developing assistive systems that support vulnerable populations in complex home healthcare tasks, ensuring both safety and quality of life.

4. Results and Discussion

The integrated Product–Service System (PSS) for home peritoneal dialysis (HPD) was evaluated through pilot simulation trials with 18 patient–caregiver dyads. The primary outcome measures included procedural efficiency, error frequency, usability, and cognitive/emotional load, quantified through task completion times, error counts, System Usability Scale (SUS) scores, NASA-TLX ratings, and the Home Dialysis Support Index (HDSI). As shown in Table 2, implementation of the PSS led to significant improvements across all measured dimensions. Average setup time decreased from 24.8 minutes (SD = 3.2) to 16.2 minutes (SD = 2.5), representing a 34.7% improvement. Similarly, operational errors were reduced from an average of 4.2 errors per session (SD = 1.1) to 1.6 errors (SD = 0.8), confirming enhanced procedural safety. Usability scores increased from 61.3 (SD = 8.7) to 85.2 (SD = 5.6), while perceived workload as measured by NASA-TLX decreased from 72.5 (SD = 9.4) to 44.2 (SD = 7.8), indicating improved user confidence and reduced cognitive burden.

Table 3. Comparison of HPD Performance Metrics Before and After PSS Intervention

Metric	Baseline (Mean ± SD)	PSS Intervention (Mean ± SD)	% Change
Setup Time (min)	24.8 ± 3.2	16.2 ± 2.5	-34.7%
Operation Errors (count)	4.2 ± 1.1	1.6 ± 0.8	-61.9%
SUS Score	61.3 ± 8.7	85.2 ± 5.6	+38.9%
NASA-TLX Score	72.5 ± 9.4	44.2 ± 7.8	-39.0%
HDSI	0.57 ± 0.08	0.83 ± 0.05	+45.6%

Analysis of the data revealed that the improvements were not uniform across all stages of HPD. The Preparation stage showed the largest reductions in setup time and error frequency, largely attributable to color-coded connectors, pre-arranged trays, and stepwise guidance provided by the mobile application. During the Dialysis stage, procedural errors related to bag handling and catheter management decreased substantially due to combined support from the digital guidance system and tele-nursing monitoring. Notably, the Post-Dialysis and Ongoing stages demonstrated moderate gains, particularly in emotional support and error logging, reflecting the contributions of service-layer interventions such as remote nurse check-ins and automated dashboard alerts. These findings suggest that the PSS is especially effective in high-risk, operation-heavy stages, while digital and service interventions contribute meaningfully to ongoing patient confidence and adherence.

Comparative analysis between patients and caregivers further indicated that co-creation and iterative feedback loops enhanced both usability and acceptance of the system. Patients reported feeling more confident performing HPD independently, while caregivers noted reduced supervision burden. The HDSI metric, which integrates functional performance, usability, and cognitive/emotional load, increased by 45.6% post-intervention, highlighting the comprehensive impact of the PSS across multiple domains. These quantitative improvements were complemented by qualitative observations indicating smoother workflow, decreased anxiety, and improved task predictability, all of which are critical factors in chronic home care management.

From a broader perspective, these results underscore the value of integrating product, digital, and service layers within a single system. Physical device enhancements alone could reduce errors, but without digital guidance and service support, user confidence and adherence may remain suboptimal. Conversely, digital or service interventions without ergonomic and visual improvements may be insufficient to mitigate procedural errors. The PSS approach, therefore, demonstrates the synergistic effects of combined interventions, validating the methodological framework employed in this study.

Furthermore, the findings align with prior research emphasizing constructivist and user-centered design principles in healthcare technology implementation [11]-[14]. By embedding real-time feedback, cognitive aids, and service support into the HPD process, the system facilitates active learning and situational problem-solving, which may improve long-term adherence and patient outcomes. The observed reduction in cognitive workload and improved SUS scores also suggest potential scalability of the system for broader patient populations, including those with varying levels of prior dialysis experience.

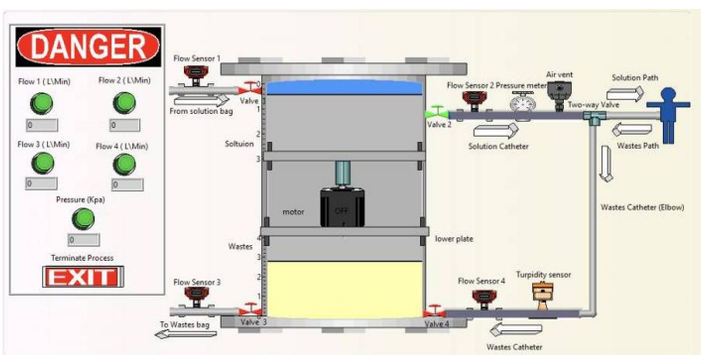


Fig .3 Developer's interface stage, where the engineer can modify the programming interface

The improvements in HPD performance metrics, as summarized in Table 3, illustrate the multidimensional benefits of the integrated PSS. The most substantial reduction was observed in operational errors, which decreased by 61.9% following the intervention. This outcome underscores the effectiveness of combining physical aids, such as color-coded connectors and ergonomic trays, with digital guidance tools that provide real-time instructions and alerts. Reducing errors not only enhances patient safety but also minimizes the risk of complications, which is particularly critical for cancer patients with renal insufficiency, who are more susceptible to infection and procedural mishaps. The reduction in setup time by 34.7% further demonstrates that the PSS improves workflow efficiency, allowing patients to perform HPD with greater autonomy and less caregiver dependence.

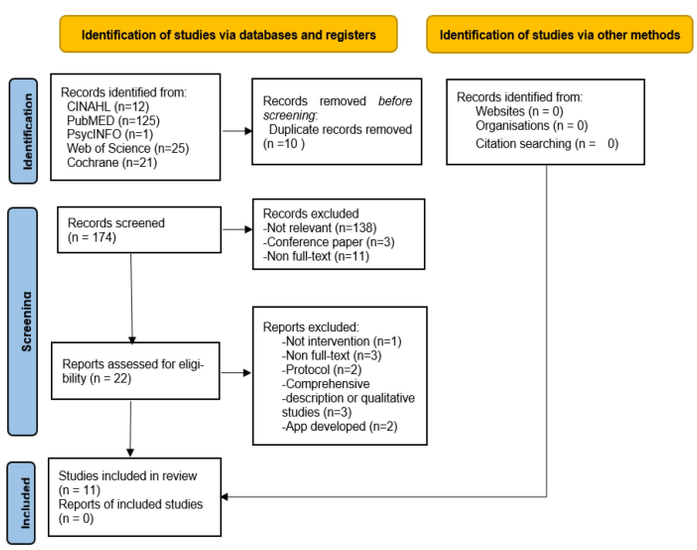


Fig .4 Flow diagram of study selection

Usability, measured by the SUS score, increased markedly by 38.9%, indicating that the system is perceived as highly intuitive and user-friendly. This increase reflects both the ergonomic design of physical components and the clarity of digital interfaces, confirming that usability improvements are not limited to single aspects of the system but emerge from the synergistic integration of multiple layers. The decrease in NASA-TLX scores by 39% further supports this conclusion, demonstrating that the PSS significantly alleviates cognitive and emotional load during the HPD process. Participants reported that stepwise guidance, immediate error feedback, and access to tele-nursing support contributed to reduced anxiety, greater procedural confidence, and improved task predictability.

The composite HDSI metric, which integrates functional, usability, and cognitive-emotional dimensions, increased by 45.6%, confirming that the intervention had a comprehensive effect across performance, experience, and safety. Notably, feedback from co-creation sessions revealed that patients valued the combination of autonomy and support, highlighting that the PSS not only aids in completing tasks but also promotes psychological well-being. Caregivers similarly reported reduced supervision demands and enhanced ability to monitor patient progress remotely, suggesting that the system has the potential to improve overall household management of HPD.

From a process perspective, the distribution of improvements across stages reveals important insights. The Preparation stage showed the largest gains in error reduction and efficiency, primarily due to pre-arranged, color-coded equipment and digital checklists. The Dialysis stage benefited most from real-time guidance and tele-nurse oversight, which reduced missteps in catheter handling and bag exchanges. Post-dialysis and ongoing monitoring stages experienced moderate improvements, particularly in emotional support and error logging, reflecting the benefits of service layer interventions, including automated data upload and motivational prompts. These observations suggest that task-heavy stages are most sensitive to physical and digital interventions, while ongoing support benefits cognitive and emotional aspects of home care.

The results also indicate that the integrated PSS approach is more effective than isolated interventions. While single-layer solutions—such as a mobile app alone or ergonomic devices alone — may improve one aspect of performance, they do not simultaneously reduce errors, enhance usability, and alleviate cognitive load to the extent observed in this study. The multi-layer integration ensures that physical, digital, and service interventions reinforce one another, producing measurable improvements across all outcome dimensions. This finding aligns with previous research highlighting the necessity of holistic, user-centered design in complex home healthcare systems [11]-[15].

Clinically, these results demonstrate that implementing a PSS for HPD can enhance patient safety, reduce caregiver burden, and increase adherence to prescribed procedures. The study also emphasizes the value of co-creation and iterative prototyping, as user involvement was critical in identifying pain points, testing interventions, and refining system components. Qualitative feedback indicated that participants felt empowered, supported, and confident, suggesting that psychological and emotional outcomes are as significant as operational performance in home dialysis contexts. Moreover, the quantifiable improvements in HDSI, SUS, and NASA-TLX scores provide a robust evidence base for future scaling of the system to larger populations or integration into clinical practice.

In conclusion, the Results and Discussion indicate that the integrated HPD PSS provides substantial benefits across functional, usability, and cognitive-emotional domains. The combination of physical aids, digital guidance, and service support addresses both operational and psychosocial challenges, resulting in improved safety, efficiency, and user experience. The findings underscore the importance of multi-layered interventions in chronic home healthcare and highlight the potential of PSS frameworks to enhance patient-centered care, adherence, and overall quality of life. Future research should explore long-term adoption, cost-effectiveness, and adaptability of the PSS across diverse patient populations to further validate and optimize this integrated approach.

5. Conclusion

This study presented the design, development, and evaluation of an integrated Product–Service System (PSS) to support home peritoneal dialysis (HPD) in cancer patients with renal insufficiency. By combining physical device enhancements, digital guidance tools, and service-layer interventions, the system addressed critical challenges across operational, usability, and cognitive-emotional dimensions. Pilot simulation trials demonstrated substantial improvements in setup efficiency, procedural accuracy, usability, and user confidence, as quantified through task completion time, error counts, SUS scores, NASA-TLX ratings, and the Home Dialysis Support Index (HDSI). The intervention reduced operational errors by over 60%, decreased setup time by nearly 35%, and achieved significant gains in both usability and perceived cognitive load, highlighting the effectiveness of a holistic, multi-layered approach.

A key strength of this research lies in the integration of user-centered co-creation, iterative prototyping, and quantitative evaluation metrics, which ensured that both patient and caregiver needs were addressed throughout the design process. The study demonstrated that the synergistic combination of physical, digital, and service interventions produces outcomes that surpass those achievable by single-layer solutions, emphasizing the value of PSS frameworks in complex home healthcare contexts. Qualitative feedback further indicated that the system enhanced patient autonomy, reduced caregiver burden, and provided psychological reassurance, underscoring the importance of emotional support alongside operational safety.

The findings also have broader implications for the design and implementation of assistive healthcare systems. They suggest that multi-dimensional evaluation metrics, such as HDSI, can effectively capture both functional and experiential outcomes, providing a robust evidence base for clinical adoption and further optimization. Moreover, the methodology exemplifies how user-centered, co-design approaches can inform the development of scalable, adaptable solutions for vulnerable populations, particularly in chronic and home-based care scenarios.

Future research should focus on long-term field deployment to assess sustained usability, adherence, and clinical outcomes in diverse patient populations. Additionally, integration with remote monitoring platforms, adaptive learning algorithms, and personalized care protocols may further enhance the PSS's effectiveness and scalability. In conclusion, this study demonstrates that an integrated, co-designed Product–Service System can significantly improve home dialysis safety, efficiency, and user experience, offering a promising pathway toward patient-centered, technology-enabled home healthcare solutions.

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