

Design Dilemmas and Development Directions of Inclusive Modularity in Multi-species Wearable Interaction Scenarios

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Abstract: The study explores design difficulties and research directions of inclusive modularity in multi-species wearable interaction scenarios. The research contends that multi-species interaction requires designers to simultaneously consider physiological variation, interspecies ethics, located activity, maintenance, and communicative context, rather than treating wearables as standardised items for a single category of user. Using inclusive design, animal-computer interaction, disability-oriented wearable research, and more-than-human design conversations as a springboard, the essay considers why modularity is appealing in theory but difficult in practice when one system must accommodate heterogeneous bodies, behaviours, and environments. It also investigates how inclusive modularity might enable adaptability, repairability and situation reactivity without turning nonhuman actors into passive extensions of human purpose. The research suggests that the future of multi-species wearable interaction lies in modular systems that are body-aware, context-sensitive, morally based, and open to iterative reconfiguration, rather than inflexible universal solutions.

Keywords: Multi-species design; wearable interaction; inclusive modularity; animal-computer interaction; more-than-human design; inclusive design.

1. Introduction

Wearable interface design has come a long way from the concept of a single human user carrying or wearing a personal device. Wearable systems mediate relationships between humans, animals, surroundings and digital infrastructures simultaneously in many emergent scenarios. This shift challenges traditional notions about who counts as the wearer, what counts as usability, and how design should respond to physiological difference.

The problem becomes even more complicated when more than one species is involved. A wearable arrangement can include pets, working animals, livestock, wildlife, handlers, carers, or mixed habitats where human and nonhuman requirements overlap but are not the same. Under such conditions, design cannot be based on a fixed template of the body or a narrow model of the task. It must include bodies, behaviours, safety circumstances, ethics and communication across species boundaries.

This study proposes that inclusive modularity is a potential but difficult path for this design dilemma. The appeal of modularity is its implication of adaptability, replaceability, and the ability to tailor to a circumstance. Yet modularity in multi-species wearable engagement also creates issues over inclusivity, stability, embodiment and ethical responsibility. On that premise, the essay elaborates on the theoretical backdrop for inclusive modularity, the fundamental design issues that inclusive modularity encounters and the development possibilities that may promote more responsible and workable multi-species wearable systems.

2. Conceptual Basis of Inclusive Modularity in Multi-species Wearables

The tradition of inclusive design is a good place to start.

Clarkson and colleagues describe inclusive design in terms of attention to the greatest feasible spectrum of users, rather than the assumed average user [1]. This perspective is crucial because it takes design beyond limited standardisation into the domains of variability, mismatch, and exclusion. Inclusive design in wearable interaction emphasises early consideration of physiological comfort, access, adaptability, and conditions for practical usage.

The second conceptual shift is the transition from human-centered wearables to multi-species wearables. Mancini's manifesto for animal-computer interaction claims that technology for animals should be informed by the animals' own settings, activities and welfare and not by human ideas alone [2]. This notion is important for wearable scenarios with non-human actors as it forces the designer to consider beyond human convenience. A wearable system is not successful just because it provides data to users.

Ritvo and Allison take on this difficulty by characterising nonhuman animal-computer interaction as design for the exceptional user [3]. Their argument is important since animals don't match the standard usability paradigms inherited from mainstream human-computer interaction. Bodies are different, sensory worlds are different, and the indicators of discomfort or preference are not linguistically reportable in the same manner. Inclusive modularity must consequently be a response to radical heterogeneity, not to simple user variation.

Mancini, Lawson and Juhlin also identify animal-computer interaction as an emerging discipline with its own design goal [4]. This reinforces the case that the multi-species wearable design is not a mere specialised application of common wearable engineering. It is a field where interaction, welfare, involvement and environmental context must be thought of simultaneously. This is where modularity helps. It gives a structural way to negotiate varied needs. But it also reveals how incomplete one-size-fits-all design truly is.

Animal-centred ethics imposes another conceptual constraint. Mancini thinks that design for animals should not be driven merely by instrumental human gain but by explicit ethical consideration of the animals concerned [5]. This is important for multi-species wearables because modular systems can quickly become extractive, connecting sensors, feedback units or control interfaces to bodies without considering burden, agency or welfare sufficiently. Inclusive modularity must therefore be seen not simply as a technical strategy but as an ethical design commitment.

Another crucial perspective is provided by Moon's discussion on wearable devices for people with disabilities [6]. The work is important in that it centers on human disability situations and promotes body variety, comfort, location, tolerance, and the risk of desertion when design does not meet living bodily realities. The lesson applies to multi-species scenarios: a theoretically flexible module can still fail if it does not account for pressure points, movement patterns, heat conditions, or the practical labour of fitting and maintaining the device.

These ideas indicate that inclusive modularity is not just an issue of detachable parts. In multi-species wearable interaction, it refers to a design logic that seeks to negotiate physiological difference, ethical responsibility, contextual use, and iterative flexibility inside a single wearable system.

3. Main Design Dilemmas

The first difficulty is the contradiction between standardisation and bodily variation. Modularity often demands some degree of standardisation in the interface, but wearables that are usable by multiple species challenge bodies that vary in size, posture, skin or fur state, movement style, and tolerances [1, 3, 6]. A module that fits nicely in embodied terms may nonetheless be inappropriate in technical terms. The conundrum designers consequently face is that modular systems demand reproducible structure, yet inclusive systems require space for irreducible difference.

The second dilemma is about welfare and utility. It is obvious from both Mancini's ACI framework and her subsequent ethical argument that technology achievement cannot be measured solely by the use of the data or the efficiency of the human task [2, 5]. In the case of multi-species wearables, modules can monitor, track, guide or communicate, but they can also impede movement, induce stress or alter routine behaviour. The problem is that functionalities that are good for human stakeholders are not necessarily good for animal participants.

Third, there is interpretive asymmetry. In human centred Interaction designers normally can obtain verbal feedback on discomfort, confusion and preference. This channel is limited or not available in multi-species contexts, making iterative evaluation much more challenging [3, 4]. Modular design may offer easy adjustment but if reliable, species-appropriate input is lacking, designers may confuse technical reconfigurability with real inclusion. The challenge is not just how to modify a module, but how to know if the modification genuinely enhances the interface.

The fourth difficulty is context instability. Multi-species wearable systems are commonly deployed in moving, outdoor, household or laborious situations rather than in controlled laboratory conditions. In their systematic analysis of wearable haptic systems, Pacchierotti et al. demonstrate that the design of wearable interactions has to be carefully considered regarding attachment methods, body positioning and user-

specific requirements [7]. In multi-species environments, such decisions are much more difficult as gadgets can be subjected to weather, dirt, impact, wetness, social contact or fast mobility. A module that looks flexible in theory could be brittle in practice.

The fifth difficulty is participatory restriction. The animal-centred design heritage encourages forms of engagement, although conditions for animal inclusion in design remain methodologically challenging [2, 4, 8]. This generates a tension at the core of inclusive modularity. Designers seek systems that are adaptive to the participant, yet the participant may not be able to engage in the design process representationally. But inclusion therefore risks becoming an interpretative claim on behalf of the nonhuman other, rather than a substantially shared creative approach.

The sixth difficulty is the size of inclusiveness. Moon's debate on access indicates that inclusive wearable design already requires considerable negotiation even within human communities [6]. Add multi-species contact, and the aim of inclusiveness explodes enormously. Designers have to decide if inclusivity means one architecture for numerous users, families of linked modules, or scenario-specific systems only partially compatible. The more inclusive the claim, the more likely it is that modularity is mere rhetoric and not workable reality.

These challenges show that inclusive modularity isn't hindered by one technical hurdle. Its challenges are the interplay of body variety, ethical uncertainty, feedback restrictions, environmental variability, and overextended design ambition. Any genuine path of development must deal with all these challenges collectively, and not in isolation.

4. Development Directions

One initial avenue of progress is to re-conceive modularity as relational rather than just mechanical. In multi-species wearable design, a module should not be evaluated just by its ability to be attached, detached or replaced. It should also be evaluated in terms of whether it maintains comfort, enables meaningful activity and honours the placed relationship between species [1, 2, 5]. This reframing helps avoid modularity being reduced to an engineering convenience.

The second direction is to employ body-aware fitting methods. The debate on the wearable design of the Moon foregrounds the issues of placement, tolerance and physical heterogeneity, whereas the ACI literature focuses on species-specific contexts and demands [2, 6]. In practical terms, this means that future modular wearables need to be developed around attachment logics, attachment zones and material reactions that are sensitive to varied anatomies and behaviours. It is more realistic to have inclusive modularity when modules are constructed from the body outwards, rather than from the circuit inwards.

A third approach is to address welfare as a design criterion rather than an afterthought. Both Mancini's ethical viewpoint and the broader ACI agenda suggest that animal welfare and beneficial interspecies relations are important in responsible technology design [4, 5, 8]. Therefore, modular wearable devices should aim for low burden, reversible attachment, easy removal and little interference with normal movement and social behaviour. A technically advanced technology that may harm wellbeing should be thoroughly reviewed and not automatically be seen as developmental progress.

A fourth direction is to enhance context-sensitive iteration. More than human design methods argue that interface design

should examine the relationships between humans, nonhuman beings and environments [9]. This broad framing is useful because it reminds designers that wearable interaction does not occur in the abstract. Future development should be directed toward recurrent small scale testing in real usage situations with regard to maintenance, cleaning, breaking, movement limits and handler habits. Scenario-sensitive claims for refinement of modules may make the ideal of inclusive modularity more successful than universal claims.

A fifth direction is the incorporation of more-than-human design thinking. Forlano's work on posthumanism and design calls for designers to go beyond limited human-centered assumptions and reflect on relations between humans, technologies, and larger surroundings [10]. For multi-species wearables it means a change from device-centric issue solving to ecosystem awareness. A module should be assessed on how it affects relationships, routines, and habitats, not only on completion of the assignment.

A sixth direction is designing for maintenance, repair and reconfiguration. Over time, multi-species wearable devices will likely wear out, get dirty, need adjustments, and job modifications. Modular design is really inclusive when parts may be cleaned, replaced, enlarged or reoriented without excessive cost or specialised intervention. Therefore, development should focus on durability and aftercare as much as on adaptability to first usage.

And the last direction is conceptual restriction. Designers should not claim that a universal modular inclusivity has been achieved if they have only examined specific application scenarios. A more responsible method is to design layered modular families, explicit about their intended species, surroundings, and constraints. That is not to say the project of inclusive design is diminished. In contrast, it renders inclusivity more realistic by anchoring it in actual interactions and realities rather than in abstract technological hope.

5. Implications for Design Practice

The foregoing research implies that inclusive modularity should be seen as a situational design technique rather than as a ready-made solution. Most useful when it helps designers to navigate difference, without rejecting difference. In reality, this means fighting the urge to construct a universal wearable platform for all bodies, species, and settings.

One consequence of this observation is interdisciplinary collaboration. The difficulties that inclusive design, ACI, accessibility-oriented wearable research, and more-than-human design discuss cannot be handled by industrial design or electronics alone [1, 2, 6 10]. Designers need to consult with animal behaviourists, veterinarians, disability researchers, carers, handlers and maintenance people. Such collaboration may enable modular decisions to better reflect embodied and contextual knowledge.

A further consequence is methodological modesty. In many multi-species contexts, the absence of simple verbal input leads designers to rely on indirect cues, careful observation and reversible experimentation [3, 4, 5]. This should result in slower and more accountable design processes. Iterative negotiation is an advantage for inclusive modularity, not for fast deployment based on speculative promises of inclusivity.

The discussion also suggests a greater precision in design communication. Positive terms like adaptable, adaptive and inclusive are often employed, yet in multi-species wearable design they might mask unsolved tensions. A system can be flexible in assembly but not in corporeal acceptance, inclusive

in intention but not in action, or adaptive in software but not in maintenance. Clearer design language would make evaluation more accountable, and future comparison more meaningful.

Finally, development should aim at coexistence rather than domination. Multi-species wearables are frequently conceived of in terms of care, labour, friendship, or observation, where technology might serve to facilitate or dominate interspecies interaction. Inclusive modularity is most promising if it contributes to sustaining safer, less obtrusive, and more negotiable types of wearable mediation. In this perspective, the most fundamental design concern is not how many modules can be added, but how can wearable systems join into shared multispecies existence.

6. Conclusion

The promise and challenge of inclusive modularity in multi-species wearable interaction situations lies in reconciling physiological variety, ethical responsibility, practical flexibility and long-term use in a single design framework. Its significance is in providing alternatives to rigid, one-size-fits-all wearable systems, but its failures occur when language outstrips embodied and contextual reality.

I have claimed in this study that the fundamental difficulties of inclusive modularity are standardisation, welfare, interpretation, participation and environmental instability. It has also indicated that future work should focus on modular systems that are body-aware, morally grounded, context-sensitive and repairable.

That is why multi-species wearable design needs to aim for inclusive modularity, with conceptual caution and practical specificity. More responsible growth will not come from universal wearable solutions but from modular tactics that recognise the heterogeneity and interdependencies of shared multispecies worlds.

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