

Decoding the Unspoken: State of Art Review and Empirical Investigations on Empathy and Efficiency in Human-Robot Interaction through Intent Sharing

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Abstract

In the coming ages due to developments in generative AI, robots are likely to become social actors. Henceforth it is important to study how can human robot communications be more empathetic, once such factor in sharing such empathy is intent detection without explicit communication. This paper reviews the current proceedings in intention detection, formulates a framework for intent detection through perception and then explores the implications and impact of humans sharing their intentions with robots before collaborative tasks, and its effects on overall efficiency and user experience. The later is conducted by a user study in a simulated environment using ROS Unity interface. At the end the impact of situational awareness context understanding for Collaborative task is outlined and a short user study is presented. The results reveal significant implications regarding empathy, boredom and intuition which forms a crucial input for designing future robotic interfaces.

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1. Introduction

Robots are becoming increasingly complex with sensors and intelligent control systems. With sensors and sophisticated controls. This change has been even more evident in recent years, with modern robots developing increasing autonomy and capability to the point where they can actively interact with a human partner toward achieving a common goal. This has led to increasing research in the area of a Human Robot Interactions (HRI), this new field of research is aimed at maximising the performance through a common platform of understanding for robots as well as humans. HRI systems enable high-level task planning and flexibility achievable with humans at centre, while still leveraging the repeatability, precision and load capacity of robots. In HRIs social behaviours, interactions with natural human and fluent partners, communication modalities and cognitive load sharing are important facets.

While much of the previous literature focuses on safety in an HRI environment, we here have a view on agency and shared collaborative control. Here we are defining foundations of sharing of sense of agency and intentional awareness between Humans and Robots in situations where physical interactions be-

tween them is crucial, they are physically coupled and are cooperating towards a shared goal. One interesting observation from the study is that the foundations of intent detection lie in rehabilitation where human intent is detected to control a robotic device that replaces lost capabilities, here its compensatory in nature, while in case of exoskeletons human intent is detected to enhance human capacity in many cases kinesthetic capacity.

These four elements (Intent authoring, intent capture, task arbitration, and Feedback retrieval) can be used to model applications requiring physical human robot interaction. For example, Moving a heavy and bulky object in tandem with the collaborative robot.

1.1. Intent Authoring

We define Intent Authoring as a way in which human is communicating its intent. To answer the question on how to sense intent? We first had to go through the psychological analysis of what exactly is intent. High level intent is defined as the human's ability to communicate the trigger for a certain action. This is often binary ON/OFF or a YES/NO state intent. As we go further deep dimensions are added. For example, high level intent can be triggering a motion. A lower level would be the direction of motion and further lower it would be direction and

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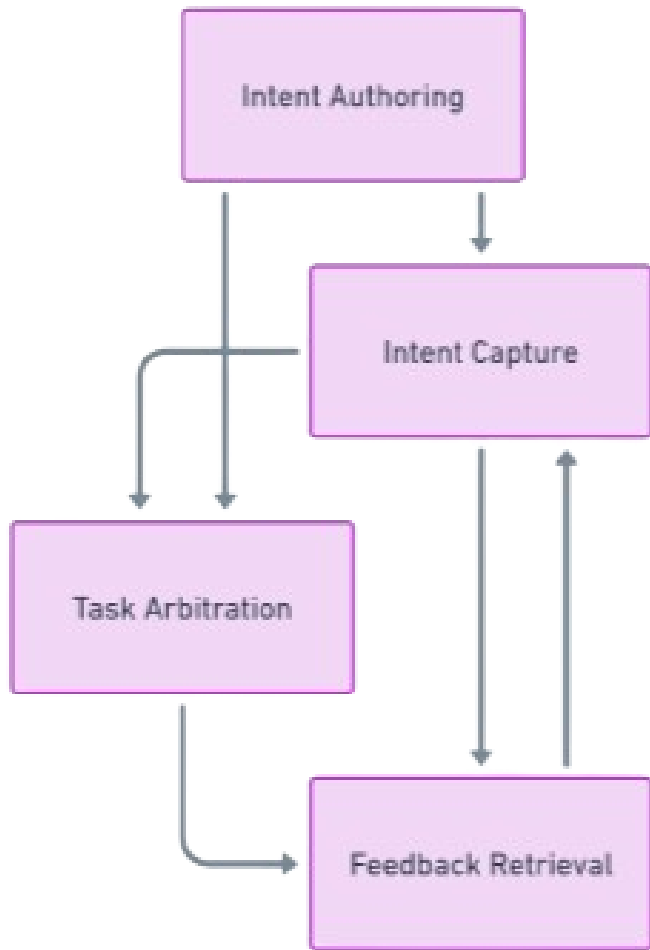


Fig. 1. The four elements of Intent Sharing.

magnitude of motion. Then direction, magnitude, velocity and so on.

1.2. Intent Capture

The component which deals with recognising an action as an intent is intent capture. In many cases the signals and the intent are not necessarily the same things but share a common frame. The design of the shared control architecture defines the quotient of intent captured based on measured signal values. For ex in ref. [1] The signal is measured from the 6 DoF force-torque sensor and intent is interpreted based on rotational and transnational movement of the robot joint. While pattern recognition approaches are appealing for their ability to learn arbitrary mappings between myographic signal features and intent information, they are most commonly used to select from a relatively small number of discrete control states. [2] The interaction forces measured in the active exoskeleton are fed into a model of the exoskeleton dynamics to predict the walker's forward path over a short time horizon. The user's state is a discrete variable representing possible walking modes, e.g., "go straight forward" or "turn to the right".

1.3. Intent arbitration

Types of role arbitration include co-activity, master-slave, teacher-student, and collaboration, which differ in the cost functions, objectives, and expectations of the human and robot agents.

Dynamic role arbitration is the ability to switch or adapt roles based on the situation, the human's intent, performance, or affective state, or the robot's confidence or prediction.

Machine learning and performance metrics are two common tools for determining when and how to change role arbitration, using data driven or task-based approaches.

Algorithms for role arbitration are methods for implementing the role arbitration mechanism, such as linear discriminant analysis, support vector machines, artificial neural networks, radial basis function neural networks, recursive least squares, hidden Markov models, and game theory.

These algorithms can be used to classify, estimate, predict, or optimize the human and robot roles based on the available sensory information and the desired task outcomes.

1.4. Feedback Retrieval

Feedback is the information provided by the robot to the human about the state of the coupled system, the characteristics of the environment, or the suggested actions or strategies for the task.

Feedback design involves choosing the [2] appropriate feedback modality, content, timing, and intensity for the given task and user. Feedback design should consider the user's preferences, abilities, and attention, as well as the task requirements, complexity, and context. Feedback design should also balance the trade-off between providing enough information to enhance the user's performance and satisfaction, and avoiding information overload or distraction.

Feedback evaluation is the process of assessing the effectiveness and impact of the feedback on the user and the task. Feedback evaluation can use objective measures, such as task completion time, accuracy, or error rate, or subjective measures, such as user satisfaction, trust, or workload. Feedback evaluation can also use physiological measures, such as heart rate, skin conductance, or brain activity, to capture the user's emotional and cognitive responses to the feedback.

2. Review of Studies on Impact of Intent Recognition or Anticipation on overall productivity

SAT model: [3]The Situation awareness-based Agent Transparency (SAT) model, a three-level model that organizes the information requirements for optimal human agent team performance. The model suggests that the agent should provide information about its current state, goals, intentions, actions, reasoning, constraints, projections, consequences, likelihood, and uncertainty to the user. This SAT model can help the user to better understand the agent's behaviors, develop shared situation awareness, and calibrate trust in the agent.

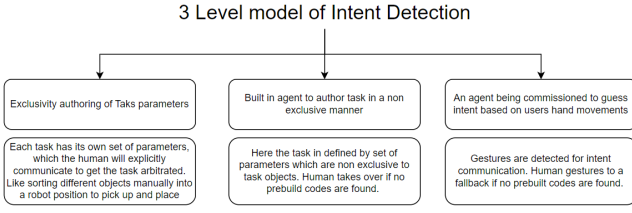


Fig. 2. Intent sharing levels defined in the task

This study [4] how intent sharing, or the communication of goals and plans, affects human-robot collaboration and trust. The authors compare three types of intent sharing: no intent, low-level intent (actions), and high-level intent (goals). They find that high-level intent sharing leads to higher team performance, situation awareness, and trust than low-level or no intent sharing. This research sheds light on the critical role of intent communication in enhancing collaboration and trust between humans and robots.

By sharing intentions effectively, we can unlock the potential for more efficient and empathetic interactions in human-robot teams. Trust is evaluated using subjective ratings and physiological measures such as heart rate variability.

The results reveal that high-level intent sharing significantly improves team performance by enhancing coordination and reducing conflicts. Participants also report higher trust in robots that transparently communicate their goals. Interestingly, individual differences, such as prior experience with robots and personality traits, moderate the impact of intent sharing. For instance, participants with high openness to experience tend to benefit more from high-level intent sharing, while those with low trust in automation show greater reliance on low-level intent information.

3. Experiment Design

Based on the above studies a 3 level experiment was designed and in person study was conducted.

1. **Explicit Command:** Where tasks have specific parameters that a human communicates explicitly to the robot—for instance, sorting objects for the robot to pick up and place.
2. **Prebuilt Task Execution:** Here, tasks are defined by parameters that are not exclusive to the objects. The human intervenes only if the robot encounters uncertainty and prebuilt responses are inadequate.
3. **Gesture-Based Intent Communication:** The robot guesses intent based on the user’s hand movements, with gestures being used for intent communication and to signal fallback actions if prebuilt codes are not sufficient.

By observing their ability to perform the task under both conditions, we aimed to gather data on the system’s impact on user experience, efficiency, and ease of use. The contrast between the experiences was fundamental to our evaluation of the project.

Level 1: Explicit Command In the first level, participants are instructed to arrange objects in specific patterns which the robot then replicates. This stage assesses the robot’s ability to execute tasks with hardcoded parameters based on direct human input.

Level 2: Prebuilt Task Execution The second level introduces an element of robot autonomy. Participants interact with a control interface to signal the robot to perform tasks with some level of prebuilt flexibility. The robot utilizes predefined algorithms to place objects according to the type signaled by the human operator, with the human stepping in only if the robot encounters uncertainty.

Level 3: Gesture-Based Communication The third and most advanced level tests the robot’s capability to interpret human gestures. This scenario requires no physical intervention from the human, relying entirely on the robot’s ability to decipher and act upon non-verbal cues.

3.1. Simulation of the Experiment

General Environment: The experimental environment for intent detection in human-robot interaction is set up with a robot in a simulated workspace where colored objects are randomly populated. The robot is programmed for pick-and-place tasks and is equipped to handle objects of two colours: Green, and Blue while the human has to intervene in case of other colours. The participants were asked to sort 10 cubes and the timing to accomplish the task in each intent detection level was noted.

Experiment Level 1: The participant engages in a task requiring spatial reasoning and manual interaction with a simulated robotic environment. The task involves clearing the workspace of potential obstacles (represented by white cubes) and sorting colored cubes green to the green target area, blue to blue, and red cubes to be discarded while avoiding collisions. Each action is initiated by the participant pressing a ‘move’ button, signaling the robot to execute the task. The participant has to wait until the action is completed and the robot is disengaged. This level assesses human involvement in error prevention and task efficiency in a controlled setting.

Experiment Level 2: Participants communicate their intent to the robot through specific keystrokes corresponding to different colored cubes. Initially, tasks mirror the prior setup with participants moving white cubes to prevent robot collisions. Upon encountering a familiar coloured cube, participants are asked to communicate their intent by pressing ‘P’ for green and ‘O’ for blue. The robot then comes to the position of cube grabs it and places it at target. No need to manually move cube to desired pickup target. The participant retains manual control in scenarios involving the red cube, directly intervening in the robot’s task sequence. This setup explores the efficacy of keyboard-based intent signaling in directing robotic action and the human’s role in overriding automated processes when necessary.

Experiment Level 3: This is very similar to level 2 with the only difference being the keystrokes here are replaced by an IMU sensor. The participants are asked to communicate its intent by moving an IMU based toy (Sphero mini). The toy registers the IMU positions and then simulated the keystrokes P, O and I. These gestures direct the robot to handle the colored

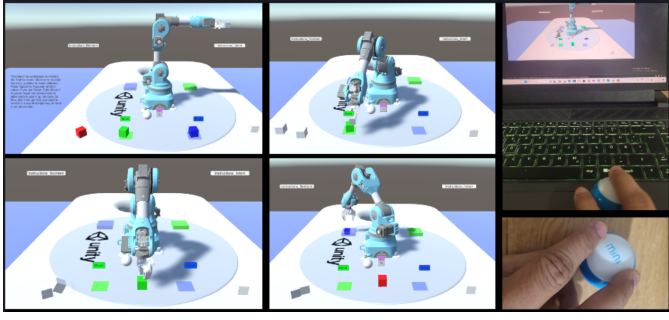


Fig. 3. Graphical Representation of Experiment Simulation, The two images on the top left indicate level 1, the two on bottom left indicate level 2, while the two images on right, with IMU toy indicate level 3.

cubes accordingly, with 'I' being the new input for red cube intervention. The human still has to take over in case white ball is populated at a random.

Using Sphero a realistic feeling of perception input is simulated. Their movement are used to track the IMU and map them to keystrokes with an 80 % accuracy. To communicate to sphero a ROS 2 node is running in background which is just simulating keystrokes and it is not connected either to Unity nor to ROS, its an independent perception input. The experiment owner manually assigns the listener ON/OFF states to avoid fluctuation in Unity environment.

3.2. NASA Task Load Index (NASA-TLX)

The NASA Task Load Index (TLX) is used to evaluate various aspects of the user experience in human-robot interaction, such as trust in the robot's capabilities, perceived robot effectiveness, time saved, and stress levels during task monitoring. We're looking for participant input on these specific elements to test our theories that intention sharing boosts the effectiveness of human-robot collaboration, boosts user trust, and eases the tension associated with close oversight of robotic tasks. The NASA TLX scores will reveal the cognitive and emotional impact of our intent-sharing interface, revealing a deeper appreciation for user workload and tension in arduous tasks.

3.3. System Usability Scale

The System Usability Scale (SUS) questionnaire will be used to complement the NASA TLX by focusing on the overall usability of the system. This includes evaluating the intuitiveness of the user interface and controls, as well as the robot's ability to adapt to the user's actions and intentions over time. High scores in the SUS questionnaire would suggest that the system is user-friendly and that the robot's responsiveness to user intent is aligned with the users' expectations. These insights will be critical in supporting our third hypothesis that intent sharing contributes to a more intuitive and adaptive human-robot interaction, ultimately leading to a more positive user experience.

4. Results

4.1. Hypothesis

At the beginning of the experiment design we had three hypothesis to validate viz.

- H1 Intent sharing does lead to a significant improvement in the efficiency of collaborative tasks in human-robot interactions compared to interactions without intent sharing.
- H2 Intent sharing does significantly reduce the stress levels of human operators during the monitoring and control of robot-assisted tasks compared to standard interaction protocols.
- H3 The incorporation of intent sharing mechanisms does significantly increase the confidence of human operators in the robot's capabilities within a human-robot interaction context.

During the experiment design two more hypothesis were added with respect to fatigue and intuitiveness of interaction

- H4 There is A significant difference in the fatigue levels experienced by human operators when engaging in human-robot interactions with intent sharing compared to interactions without intent sharing.
- H5 Intent sharing does significantly improve the intuitiveness of the interaction between humans and robots in human-robot collaborative tasks.

4.2. Hypothesis questions

The hypothesis results are based on an average score of the below questions:

- H1 – How effectively do you feel the robot completed the task?
- How much time do you think was saved when compared to base line of manually doing the task?
- H2 – How stressed did you feel during the task?
- H3 – How predictable did you find the robot's behavior in completing the task as intended?
- How confident were you in the robot's performance during the task?
- H4 – Did the interaction with the robot contribute to your level of fatigue?
- H5 – How intuitive was the process of communicating your intent to the robot?
- How much effort was required to ensure the robot understood your intent?

Table 1. Comparative Results of Studies

Hypothesis	1st-Study		2nd-Study		3rd-Study		1st vs 2nd		2nd vs 3rd	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	t-Value	p-Value	t-Value	p-Value
Improvement in Efficiency	2.67	0.91	5.32	1.36	4.28	1.01	5.12	0.0001	1.94	0.06
Stress Reduction	2.65	2.48	5.67	1.20	4.31	1.84	3.47	0.0042	1.96	0.06
Improved Confidence in robots	2.33	0.98	4.37	1.06	4.28	1.01	4.47	0.0003	0.19	0.84
Reduced Fatigue	2.53	1.75	5.67	1.20	4.28	1.01	4.68	0.0003	2.8	0.012
Improved Intuitiveness	4.31	1.84	4.37	1.06	5.87	0.99	0.09	0.93	3.27	0.0043

4.3. NASA TLX Score analysis

The questionnaire was designed for a scale on 1-7 with 1 being worse and 7 being best response for respective questions. Table represented here 1 gives a mean score with std deviating for the average scores for individual questions for respective hypothesis. The sample size is 10 and the populations contains a mix of people from various backgrounds.

- +H1 There is a significant improvement from the 1st to the 2nd study ($p = 0.0001$), suggesting that the changes implemented in the 2nd study greatly enhanced efficiency. However, the difference between the 2nd and 3rd study is not significant ($p = 0.06$), indicating that the additional modifications in the 3rd study did not statistically improve efficiency compared to the 2nd study.
- +H2 The results show a significant reduction in stress from the 1st to the 2nd study ($p = 0.0042$). The difference between the 2nd and 3rd study is not significant ($p = 0.06$), indicating that stress levels did not significantly change with the interventions between these two studies.
- +H3 There is a significant increase in confidence in the robots from the 1st to the 2nd study ($p = 0.0003$). However, there is no significant change in confidence between the 2nd and 3rd study ($p = 0.84$), suggesting that the level of confidence reached a plateau.
- +H4 Participants experienced significantly less fatigue in the 2nd study compared to the 1st ($p = 0.0003$). There is also a significant reduction in fatigue from the 2nd to the 3rd study ($p = 0.012$), which means that the 3rd study introduced some elements that further reduced fatigue compared to the 2nd study.
- H5 The intuitiveness of the interaction did not significantly change from the 1st to the 2nd study ($p = 0.93$), but there

was a significant improvement from the 2nd to the 3rd study ($p = 0.0043$). This suggests that changes were made in the 3rd study greatly improved the intuitiveness of the system.

4.4. System Usability Score

- Frequency of Use: The score of 3.4 suggests that users are somewhat reluctant to use the robot frequently, indicating a lack of appeal or ease that typically encourages regular use.
- + Complexity: A score of 7.6 for complexity suggests that users find the robot to be on the complex side, which could be a barrier to smooth operation and quick adoption.
- + Ease of Use: Conversely, a score of 9 for ease of use indicates that once users overcome the initial complexity, they find the robot very easy to use, possibly due to intuitive design elements.
- + Technical Support: A score of 4.7 implies that users feel moderately independent in operating the robot, with occasional need for technical support.
- + Integration of Functions: A score of 7 shows that users find the robot's functions to be reasonably well integrated, though there is room for improvement in terms of cohesion and user experience.
- + Consistency: The score of 5.6 for inconsistency suggests that users encounter a moderate level of unpredictability in the robot's performance or interface.
- Cumbersomeness: A high score of 8 indicates that users find the robot quite cumbersome to use, which could be due to the robot's physical design or the way interactions are managed.
- + Confidence in Use: With a score of 7.3, users feel fairly confident in using the robot, which is positive for the system's perceived reliability and effectiveness.
- + Learning Curve: Lastly, a score of 4 for the learning curve indicates that users do not feel overwhelmed by the amount of new knowledge required, suggesting that the system is relatively easy to learn.

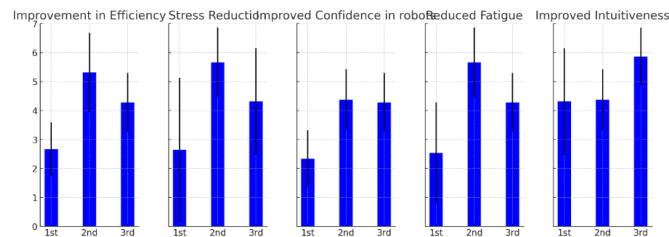


Fig. 4. Graphical representation of scores from questionnaire

4.5. Potential Risks:

- Complexity in Error Handling: The lack of significant improvement in some areas suggests that when errors oc-

cur, they may be more complex to resolve due to the advanced nature of the interaction system. Users may not be adequately prepared to take over when the system fails to interpret intent correctly.

- **User Frustration and Disengagement:** If the system does not consistently improve user confidence or if stress levels plateau, users may experience frustration, which could lead to disengagement or rejection of the robotic system.
- **Misinterpretation of Intent:** While the studies show improvements in intuitiveness, any misinterpretation of intent due to system inaccuracies could lead to errors in task execution, potentially causing safety concerns or material waste.
- **Privacy and Security Concerns:** The use of intent sharing mechanisms, especially those based on gestures or movements, could raise privacy concerns if the data is not properly secured. There is also the risk of unauthorized access or manipulation of the system.

4.6. Quantitative Insights:

Only one variable i.e time taken to complete the experiment was measured.

- **1st Scenario:** The average time was 2 minutes and 42 seconds. This is a time consuming task and also a learning curve is associated for people to get used to the game environment.
- **2nd Scenario:** The average time is 1 minute and 34 seconds, which is notably quicker. This is due to the fact that there is quite a little manual intervention. And Intent detection is indeed improving time productivity.
- **3rd Scenario:** Surprisingly the average time here is 2 minutes and 50 seconds, which is slightly longer than the first scenario. This is due to the fact that there was a 20 % error rate during intent recognition, also a leaning curve using new interface.

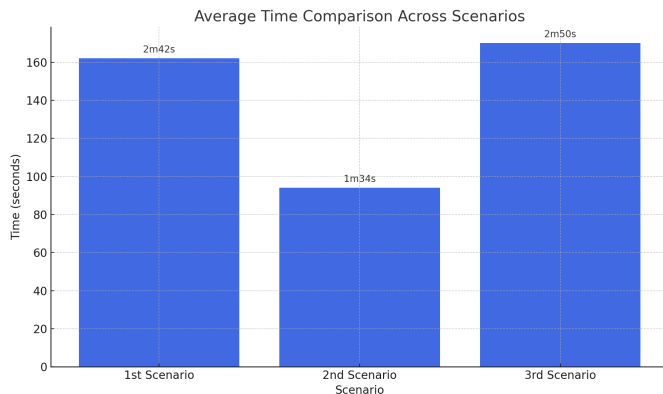


Fig. 5. Average time taken to complete the experiments

4.7. Observational Insights:

- **Scenario 1 (Fatigue and Boredom):** Participants reported fatigue and boredom in the first scenario, which appears to have been the least engaging. This could indicate that the task was either repetitive or demanded prolonged concentration without providing adequate mental stimulation. Adding more tasks or including elements that break up the routine and keep users interested can boost the user experience.
- **Scenario 2 (Comfortable Connectivity):** In the second scenario, participants were more comfortable interacting with the robot. A more user-friendly design, a better comprehension of tasks, or a more effective intent-sharing process could be responsible for this ease of mind.
- **Scenario 3 (Learning Curve and Non-Intuitive Manual Intervention):** The third scenario introduced an IMU-powered toy for intention sharing, which, while initially confusing, but it turned to be fun and game-like once the learning curve was overcome. The necessity to adjust the device when switching from the sphero to manual operation caused annoyance and was deemed un-intuitive. It is suggested that there needs to be a seamless transition between control modalities to maintain user satisfaction and system intuitiveness.

5. Discussion

The experimental studies conducted have provided valuable insights into the state of intent detection in human-robot interaction. Across different scenarios, intent sharing has been shown to improve efficiency and user experience when well-integrated into the system. However, the transition to more complex intent detection mechanisms, while beneficial in terms of engagement and intuitiveness, has also introduced challenges, especially in the ease of transitioning between interaction modalities.

In the initial scenario, the reported fatigue and boredom highlight the necessity for HRI systems that are not only efficacious but also engaging. The second scenario's positive reception emphasizes the importance of comfort and ease of use in HRI design. It is possible to create enjoyable and immersive experiences with the use of sophisticated interaction methods, such as the use of IMU-based devices, although there is a noted learning curve and some frustration due to non-intuitive manual interventions.

6. Conclusion and Future Direction

The findings from these studies indicate that intent sharing is a critical factor in enhancing HRI. However, it is clear that the benefits of such systems must be weighed against their complexity and the potential for user fatigue and frustration. Systems must be designed not only with technical efficiency in

mind but also with a focus on user engagement and the minimization of cognitive load.

In the future, there are many ways to make HRI better at detecting intentions.

Future research should look at how to make behavioral authoring tools that make it easier to program and interact with robots. This could use machine learning to change how users behave or what they like over time.

Advances in probabilistic models for intent detection could help users understand their actions and intentions better, especially in complex and dynamic environments.

To make cobots safer, it's important to make sure users are safe. Researchers should work on systems that can detect when robots are trying to do something and avoid accidents. This will help robots work well with humans and be safe.

It's also important to know how intent detection affects the way humans and robots feel about themselves. Does good intent detection make people think robots have more power? How does this affect trust and working together? By asking these questions, HRI systems can be easier to use and more reliable.

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