Opportunities and Risks of Incorporating LLMs in the Systems Engineering and Design Workflow: A Case Study of Robotic System Design Process

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Motivation

- Rapid diffusion and popularization of Large Language Model (LLM) based applications, like ChatGPT and pi.AI, has highlighted the potential to bring advanced automation to knowledge work.
- Opportunities:
 - Relieve drudgery
 - Brainstorming aid
- Risks:
 - Deceptive errors
 - New threat vectors
- Need:



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 Systematic research seeking to understand and characterize the types of knowledge tasks where LLMs can be particularly helpful and new classes of pitfalls.

Our Approach

Observed the *process* of a moderately skilled engineer working with ChatGPT to design an autonomous positioning gripper.



- Important to record full screen (not just chat history) to understand types of interactions. This process generated hours of video to transcribe.
- Presentation focuses on preliminary results.



Results Overview

- Can ChatGPT generate a reasonable solution to the design problems on "its" own?
 - Not in our data. Responses were generic and not tailored to the specific prompts.
- Where are the opportunities?
 - Generating alternatives at the paradigm or component level
 - Combating design fixation
- What are the weaknesses?
 - Tracking hard constraints / image generation
 - "Remembering" the design sequence
- What are the risks?
 - False sense of security
 - Different signals of errors (vs. novice)
- Were our HAI teams better than the engineers alone?
 - The engineers think so...

Patterns of co-design



- Once the subject realized that just uploading a PDF wouldn't yield useful input from ChatGPT they started breaking down the task.
- The problem naturally lent itself to disciplinary breakdown (mechanical, electrical software/control) and functional breakdowns (attaching vs. positioning).
- Within branches, cycled through generating alternatives, and making selections towards progressively detailed embodiment.
- The subject made all the required tables and figures based on ChatGPT input and built the submission document from those components and GPT-generated text.



Examples of progression (overall)

Subject: [...] let's start by designing the actual physical SPAM system

ChatGPT: Certainly! [...]

1. Attachment Mechanism

The attachment mechanism must securely grasp the ISS Handrail, considering its specific discorectangle shape with straight sides of 15.88mm and semicircle ends with a radius of 9.58mm.

Design Options:

- **Clamping System**: A clamping mechanism that conforms to the handrail shape.
- **Magnetic Attachment**: Utilize magnets, considering the handrail's aluminum material.
- **Combination**: A combination of clamping and magnetic forces for added security.

At the top-level, ChatGPT templated the design process and gave reasonable generic approaches for each. This is not an exhaustive list, but reminded our subjects of alternative options to pursue

Examples of progression (more detail)

Subject: can you give a more detailed explanation of the design you've come up with?

ChatGPT: Certainly! [...]

1. Attachment Mechanism

The attachment mechanism must securely grasp the ISS Handrail, considering its specific discorectangle shape with straight sides of 15.88mm and semicircle ends with a radius of 9.58mm.

Design Options:

- **Clamping System**: A clamping mechanism that conforms to the handrail shape.
 - **Jaw Design**: Two adjustable jaws designed to conform to the handrail's discorectangle shape. The jaws will have curved and straight sections to match the handrail's 15.88mm straight sides and 9.58mm radius semicircle ends.
 - **Actuation**: Utilize stepper motors or servo motors to control the opening and closing of the jaws, ensuring precise attachment.
 - **Sensors**: Include force and position sensors to detect proper attachment and provide

When asked for more detail, ChatGPT broke the generic approach into still-generic subsystems, capturing text from the original prompt.

Combination: A combination of clamping and magnetic forces for added security.



Examples of progression (more detail)

ChatGPT: Please let me know if you'd like further details on any specific component or if you have any feedback or ideas to enhance the design!

Subject: this seems good, let's focus for now on the 1st part, the attachment mechanism

At this point, the response starts to look substantive, but it's still quite generic "jaws will be adjustable".

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- ****Clamping System****: A clamping mechanism that conforms to the handrail shape.
 - **Jaw Design**: Two adjustable jaws designed to conform to the handrail's discorectangle shape. The jaws will have curved and straight sections to match the handrail's 15.88mm straight sides and 9.58mm radius semicircle ends.
 - **Shape**: The jaws will be designed to match the handrail's discorectangle shape, with straight sides of 15.88mm and semicircle ends with a radius of 9.58mm.
 - **Adjustability**: The jaws will be adjustable to ensure a secure fit without damaging the handrail.
 - **Padding**: Consider adding soft padding or coating to prevent scratches or damage to the handrail.
 - **Actuation**: Utilize stepper motors or servo motors to control the opening and closing of the jaws, ensuring precise attachment.
 - **Sensors**: Include force and position sensors to detect proper attachment and provide feedback to the control system.

© Zoe Szajnfarben/Szajniaab*: Select materials that provide strength and durability without damaging the ha&dra

Examples of progression (selections)

Subject: can you describe in more detail how the jaws would be actuated and how they would connect to each other and to whatever linkage is needed?

ChatGPT: [...]

Jaw Structure

- **Shape**: The jaws would be shaped to match the handrail's profile, with curved and straight sections.
- **Connection Points**: The jaws would have connection points for the linkage system, such as threaded holes for the lead screw nut or slots for the rack.

It takes a little more back and forth, with the subject asking specific questions to flesh out the design. At this stage ChatGPT provides concrete specs and picks a motor.

Human: okay in that case can you select a suitable motor for us to use and explain how it would be attached to the lead screw mechanism as well as how the jaws would be attached to the lead screw mechanism?

ChatGPT:

Specifications:

- **Type**: Stepper Motor (for precise control)
- **Torque**: Sufficient to overcome the friction and load of the lead screw and jaws (e.g., 0.5 to 1 N·m, depending on the lead screw and jaw design)
- **Step Angle**: A smaller step angle for higher precision (e.g., 1.8° per step)
- **Voltage and Current**: Compatible with the SPAM system's power requirements
- **Shaft Size**: Matched to the lead screw or coupling (e.g., 5mm or 8mm diameter)

Example Selection:

- **Model**: NEMA 17 Stepper Motor - **Torque**: 0.59 N·m - **Step Angle**: 1.8° - **Shaft Diameter**: 5mm



Examples of subtle difficulties

ChatGPT: [...]

Attachment Method:

- **Lead Screw Nut**: A nut that travels along the lead screw will be attached to the jaws. As the lead screw rotates, the nut (and jaws) move linearly.
- **Custom Adapter**: A custom adapter or bracket may be designed to connect the lead screw nut to the jaws, ensuring proper alignment and movement.
- **Guidance System**: Guidance rails or slots will guide the jaws' movement, ensuring parallel alignment with the handrail.

Subject: would this design allow for the jaws to both open and both close in unison or would they both just slide back and forth together? [necessary for this problem]

ChatGPT: The design I described earlier would indeed cause the jaws to slide back and forth together, as it's based on a single lead screw mechanism. I apologize for the oversight. To achieve the desired functionality where both jaws open and close in unison, we'll need to modify the design. Here's an updated approach: [...]

Subject: would using a single lead screw mechanism and 2 lead screw nuts (one with a left-handed threading) allow us to achieve our desired motion?

As the design progresses more inconsistencies arise: picks a motor that mixes a few specs, changes beam lengths, proposes a mechanism that doesn't match the requirements. Also an instance of subject and ChatGPT working together.



Less subtle difficulties

ChatGPT: Here's an image of the Smart Positioning and Attachment Mechanism (SPAM) system in its stowed position [...] Please review this image and let me know if it meets your requirements or if you'd like any adjustments or additional design drawings.

Subject: the images you generated showed a person, not a robotic SPAM system

ChatGPT: I apologize for the confusion. It seems there was a misunderstanding in the generation of the image. [...]. Let's generate the correct image:

Subject: that wasn't any better. if you can't generate the images for me properly, then can you describe to me what our SPAM would look like in the stowed position so that I can draw it? be detailed because I don't know what it should look like at all but I need to be able to draw it by hand

MixerBax ImageGen

Smart Positioning and Attachment Mechanism (SPAM) system in stowed position, featuring articulated arm with segments and omni-directional joints, adaptive gripper with magnetic pads, sensors, power and control components, motor drivers, connectors, and protection circuits





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Less subtle difficulties

ChatGPT: Here's an image of the Smart Positioning and Attachment Mechanism (SPAM) system in its stowed position [...] Please review this image and let me know if

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mart Positio aturing artic ith magnetic onnectors, a	ning and Atta culated arm wi pads, senso ind protection	chment Mechanis th segments and rs, power and con circuits	m (SPAM) sys omni-directior trol componer	stem in stowed p nal joints, adaptiv nts, motor drivers	osition, ve gripper s,
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π	ChatGPT
ac	Certainly! I apologize for the confusion earlier. Here's a detailed description of the Smart Positioning and Attachment Mechanism (SPAM) system in its stowed position, which you can use as a guide to draw it by hand:
Sub a rc	<pre>### 1. Articulated Arm: - **Segments:** The arm consists of multiple segments, each shaped like a cylindrical tube. In the stowed position, these segments are retracted and aligned, forming a compact, straight structure. - **Omni-Directional Joints:** Connecting the segments are omni-directional joints that allow movement in multiple directions. These joints resemble small spheres or ball-and-socket joints. - **Fluidic Actuators:** Located within the segments, the fluidic actuators are hidden from view but may have visible hydraulic lines running along the arm.</pre>
	<pre>### 2. Adaptive Gripper:</pre>
	### 3. Sensors: - *∗Position and Force Sensors:*∗ Small sensors are embedded along the arm and gripper. These can be represented as tiny dots or protrusions.
C	### 4. Power & Control Components: - **Electronics Box:** A rectangular box houses the power and control components. It is attached to the base of the arm and may have various connectors, wires, and LED indicators. - **Motor Drivers:** These are housed within the electronics box but may have cooling fins or vents visible on the exterior.
W	<pre>### 5. Connectors and Protection Circuits: - **Power & Data Connector:** A robust connector for power and data is located near the electronics box. It may have a cable leading to an external power source. - **Protection Circuits:** These are internal components and may not be visible in the stowed position.</pre>
[].	 #### Overall Appearance: **Color and Material:*** The SPAM system may have a metallic appearance with a combination of matte and glossy surfaces. Common engineering colors like silver, black, or gray can be used. **Size and Proportions:** The stowed position is compact, with the arm retracted and the gripper closed. It should look sleek and ready for transport or storage.
Su	<pre>### Drawing Tips: - Start with the straight, cylindrical segments of the arm. - Add the omni-directional joints between segments. - Draw the gripper at the end of the arm, with closed fingers and visible magnetic pads. - Add the electronics box, connectors, and other details.</pre>
In	 - Use shading and texture to represent the materials and finishes. I hope this detailed description helps you create an accurate drawing of the SPAM system in its stowed position. Feel free to ask for any additional details or clarification!
W	ha

that I can draw it? be detailed because I don't know what it should look like at all but I need to be able to draw it by hand



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Better as a Team

- ChatGPT made many aspects of the design process quicker and templated the set of decisions to make.
 - This enabled the human to focus on key decisions at the cost of a relatively generic high-level architecture.
- ChatGPT is excellent at generating alternatives, but not as good at making selections
 - Recurring issue of "forgetting" problem constraints and making a new selection even after a decision had been made.
 - Very efficient at "looking up" parts, but not high confidence that they're real.
- ChatGPT always "enthusiastic" and "confident" in generating reasonable looking answer, some of which were incorrect.
 - Subject with limited domain expertise felt it impossible to make independent judgement.
 - Subject with more domain experience felt comfortable correcting and reorienting to continue making progress.
- Seems to be most helpful for engineers with mid-level experience, where guidance is appreciated but capable of spotting issues.
- Next steps: Systematic coding of transcripts to characterize interactions.



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Questions?

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