ME 366J MECHANICAL ENGINEERING DESIGN METHODOLOGY

Walker Department of Mechanical Engineering | The University of Texas at Austin
Course Schedule | Spring 2022 | Dr. Zhenghui Sha

Semester-Long Design Project
Project Proposal Due: ~~February 8~~, February 13, 2022, 11:59 PM on Canvas
Project Design Review Due: ~~March 1~~, March 6, 2022, 11:59 PM on Canvas
Final Written Reports Due: May 6, 2022, 11:59 PM on Canvas
Milestone Reviews: In Lab on March 7/8, March 28/29, and April 13/14
Final Presentations: April 29, May 2, May 4, 2022, during Lecture Times
Design Showcase: April 29 – May 4 during Lab Times

Objective: This assignment provides an opportunity for you to apply your science and engineering knowledge, along with your teamwork and communication skills, to solve a challenging engineering design problem in a systematic way.

Your mission is to design, prototype, and test a robot personal assistant for grocery shopping

A robot personal assistant can be defined as artificial intelligence that helps you with day-to-day household tasks, making your life easier. They are designed to take the daily tasks that make your life more stress off your hands. In this project, you are asked to design, prototype, and test a robot personal assistant to help customers with various activities in grocery shopping. Potential users could be children who need help fetching items placed on high shelves, seniors who need help opening refrigerator doors, or disabled people who use wheelchairs, thus having no adequate forward reach at counters and tables. In a recent study by a group of European researchers, for example, if adding the disabled, the elderly, pregnant women, and couples with children, it is found that between 30 and 40% of all Europeans could benefit from improved accessibility. In addition to those people with reduced mobility due to disability or injury, many people without mobility issues could benefit from assistance in carrying heavy bags. Therefore, there are ample design opportunities. <u>Your challenge is to develop an **inexpensive** robotic system that is **easy** and **safe** for people to operate and control during their grocery shopping for an improved in-store shopping experience.</u>

At the end of the semester, your robot personal assistant should demonstrate the following capabilities:

(1) It should assist humans in at least one identified activity in grocery shopping (in physical stores, not online shopping). Human intervention and control (e.g., button or voice control) are preferred. Fully autonomous robots can be accepted.
(2) The robot personal assistant cannot be an information system and must be a mechatronic system. For example, you cannot develop software or APP for your smartphone. But, of course, you can design your system to be smartphone compatible, but your smartphone will not count toward your budget.
(3) It should be safe to operate in a grocery store. Therefore, collision avoidance must be taken into account. Yet, automatic collision-avoidance mechanisms are not required. Safety includes operational safety, such that the machine minimizes the likelihood of hitting or electrical shocking the customer.
(4) It should be easy for an average knowledge of the target users to use. At a minimum, ease of use should consider the time and frustration involved in using the system for the first time, checking in/out the device.
(5) There is no specific dimension requirement for your device. But you have a budget limit ($250) which may influence your decisions on dimension.
(6) An average DIY enthusiast should be able to build your device in a weekend, assuming that all of the off-the-shelf components (motors, wires, controllers, materials) are already on-site and that they have access to a maker space with capabilities equivalent to the Texas Inventionworks. Step-by-step instructions for building the device are a part of your project deliverables at the end of the semester.
(7) Note that many other requirements could be necessary for the marketability of the equipment and the DIY instructions for it; it is your team's job to identify those additional requirements based on your

design objective, target users, and market segment; and incorporate as many as possible into your design. An example is reliability.

(8) Identifying the number of functionalities and the development of the success metrics are part of your design project. Your design must have realized at least one mechanical functionality to help a customer with one particular physical activity. For example, help a customer to pick an item from a shelf and place the item in the cart. Simply following a customer and providing on-demand information is not enough. If your team would like to pursue additional functionality that goes beyond the basic requirements, you are encouraged to do so. Speak to your TA and/or professor about potential bonus points for additional functionality.

(9) Bonus points: "Best of" awards will be identified at the end of the semester for exceptional creativity, functionality, industrial design, and other impressive attributes.

As in any real-world design activity, your team must operate under several constraints:

(1) You may purchase all of your individual electro-mechanical and powertrain components (e.g., motors, microcontrollers, batteries, wiring, wiring connectors, gears, chains, wheels, shafts), fasteners (e.g., screws, bolts, zipties), and raw materials (e.g., wood, pipe). All other aspects of the equipment (e.g., frame, fixtures) must be made by your team with commonly available tools. No "kits" are permitted. For example, you cannot buy a wearable device, such as a smartwatch, and build an APP working as a personal shopping assistant. All components must be purchased individually.

(2) Your total budget for purchased items **must not exceed $250** per team. **The department has generously agreed to provide funding up to $150/team** with the teams supplementing the rest of the $250 budget. Your lab TA will provide you with further instruction on how to request funds and place orders. I strongly discourage you to purchase anything until mid-semester (sometime after the design review is due) when your team has a leading concept. Otherwise, you will be locked into a design and sink money into a concept that you haven't yet formally evaluated and selected.

(3) At the end of the semester, you will submit a detailed bill of materials with receipts to document your expenditures. If you borrow electro-mechanical or powertrain components from other sources, you must include their as-new purchase price in your bill of materials and count it towards the $250 limit. If your share of your team's budget creates a personal hardship for you, please speak with the professor as soon as possible to discuss options.

(4) Your team will include **approximately five team members**. Team formation will be discussed in both lectures and lab sessions.

(5) The basic performance will be evaluated with a design showcase at the end of the semester. At the showcase, your equipment will be expected to work well according to the criteria listed above and any other factors that affect its marketability (or lack thereof).

Throughout the semester, your teaching team will help you design your robot personal assistant systematically and communicate your results clearly in written and verbal formats. Please work towards the following deliverables:

1. Project Proposal (Due: ~~February 8~~, February 13, 2022, 11:59 PM on Canvas)

Perform task clarification for your design challenge, culminating in a comprehensive requirements list and design problem statement to guide the rest of your design process. At a minimum, your proposal should include the following components:

(a) Develop a Gantt chart for the semester-long project. Utilize this project assignment to identify some of your major tasks throughout the semester. Accompany the Gantt chart with a detailed task list for this project proposal (i.e., the tasks that must be completed by February ~~8~~, 13). Both the Gantt chart and the task list should be included in the appendix of your project proposal.

(b) Gather background information on your project. First, educate yourself on the existing state of the art in robot personal shopping assistants and any trends or technology gaps you can find. Then, educate yourself and your reader on the various technologies and components that might apply to the challenges of your project. (How do they work? What are the typical components, and how are they integrated? What are the relative advantages and limitations?). Utilize references (e.g., patents, books, articles, websites), and cite all of your references in the text (in APA style). **Do NOT propose**

a final design or layout for your device in your proposal; that step will come later. Just talk about the advantages and limitations of pre-existing components and systems in the context of your design challenge. Your appendix should include pictures, notes, patents, and any other information that documents your background review.

(c) Gather customer needs for your project by performing needs analysis research to identify the characteristics that customers might like or demand, including usability and safety. Design your own needs analysis research approach, which should include personal interviews (at least 5-10 interviews; Zoom is OK); observations of grocery stores, their layout, customers, salespeople, cashier, or any other potential stakeholders; a thorough investigation of the context in which the equipment will be used; systematic reviews of articles, blogs, and other written sources; and any other approaches (e.g., try experiencing existing robots) that might help your team obtain a comprehensive understanding of potential customer needs. Summarize your results in a customer needs list (weighted and categorized) in the appendix. Also, as part of this step, identify at least one customer, preferably someone unaffiliated with 366J this semester, who will serve as your *primary customer* and to whom you (ideally) could donate the finished prototype at the end of the semester.

(d) Translate customer needs into engineering requirements/specifications for your project using a House of Quality (HoQ). Your needs and requirements/specifications should cover the basic functionality described in the introduction to this assignment and all of the needs gathered in part (c). In the top and bottom of your HoQ, include metrics and targets, respectively, for your engineering requirements/specifications. You are not required to complete the roof matrix or benchmark your design against pre-existing equipment. Your appendix should include a detailed HoQ. (Tip: make sure the HoQ is readable; you may need to stretch it across more than one page if the text is too small.)

(e) Document all of your engineering requirements/specifications in a requirements list. Your appendix should include the requirements list.

(f) Write a problem statement that succinctly summarizes the goals and constraints facing your design team and serves as motivation for the rest of the design process. The problem statement should be no more than a paragraph (2-4 sentences). It should appear as the final section of your written proposal.

Writing tips: Write your proposal as if it were the first section of a final report for your entire semester-long design project. You will combine your proposal with your design review to form your final report in May. Limit your design proposal to **a maximum of 10 pages** of text with standard 1-inch margins, double line spacing, and 11 point font. You may place supplementary items such as equations, the House of Quality, and the requirements list in well-organized and clearly labeled appendices that are referenced from the main text itself (and do not count in the page count).

2. Project Design Review (Due: ~~March 6~~, March 11, 2022, 11:59 PM on Canvas)

Perform conceptual design of your equipment, culminating in one or two well-justified leading concepts. At a minimum, the conceptual design process should include the following components:

(a) Update your Gantt chart and generate a detailed task list for the project design review (i.e., the tasks that must be completed by March ~~1~~, 6). Include them in the appendix of your design review.

(b) Generate multiple distinct concepts for your equipment. Generate at least as many distinct concepts as there are members of your team. *Distinct* concepts should achieve the desired functionality in substantially different ways or arrange components in substantially different ways. Small changes in size, color, or appearance do not count as distinct concepts. Ask your TA or professor if you have questions about whether a concept is distinct.

   i. Begin by creating a functional model of your system to decompose the problem into subproblems.
   ii. Generate concepts for the critical subproblems. Use at least two of the following methods to generate ideas, focusing on the critical subsystems: mind mapping, 6-3-5, TRIZ, design by analogy.
   iii. After generating ideas yourselves, search prior art to identify additional candidate solutions for critical subproblems.
   iv. Create a morph matrix to generate concepts for your overall system. Use your functional decomposition to identify categories for your morph matrix. Use the concepts you identified in

part (a) to populate your morph matrix. Mix-and-match solutions to generate promising concepts for your overall system.

v. Optional: Starting with the concepts identified from your morph matrix, perform another round of idea generation on the overall system to generate layouts for your distinct concepts. These layouts may go beyond those identified from the morph matrix. Start with 6-3-5, but you may also use any other idea generation technique that you find useful.

vi. End with at least as many distinct design concepts as there are members of your team. Provide neat, labeled sketches of each concept.

vii. At a minimum, the appendix should include the functional model, the intermediate results of each concept generation method, the morph matrix, and the final concept sketches.

(c) Screen candidate designs using a Pugh chart. Use your requirements list to identify an appropriate and comprehensive set of criteria for the Pugh chart. Perform back-of-the-envelope estimation to evaluate criteria that cannot be determined from published technical specifications. Include cost as one of your criteria, and estimate it with a rough budget. Identify 1-3 leading concepts from your Pugh chart.

(d) Create a low resolution prototype of at least one of your leading concepts. Get feedback from potential users outside your team (ideally including the primary customer you identified in your proposal). Update your leading concept(s) as needed.

(e) Based on your Pugh chart and low resolution prototypes, clearly describe the additional modeling and experimentation efforts that are needed to further develop and validate your leading concept(s).

Writing tips: Write your design review as if it were the next section of your final report, following the design proposal you wrote in September. You will merge your proposal and design review into the final report in December. Limit the text in this design review to a maximum of 15 pages of text with standard 1 inch margins, double line spacing, and 11 point font. You may place supporting documentation (e.g., copies of your calculations, Pugh charts, concept drawings) in clearly labeled appendices that are referenced from the main text itself.

3. Final Report (Due: May 6, 2022, 11:59 PM on Canvas)

Perform embodiment design and create a working prototype of your equipment. At a minimum, the embodiment design and fabrication process should include the following components:

(a) Return to your leading concept(s) from your design review and your requirements list from your design proposal. Clearly describe the tasks that need to be performed to characterize and successfully prototype your leading concept(s). Create a Gantt chart and task list for those tasks for the rest of the semester. Review your plan with your TA. Based on that discussion, you may down-select to a single concept or entertain multiple concepts. If you down-select, update the Gantt chart and task list accordingly.

(b) Generate clearly labeled 3D sketches (or CAD drawings) of your leading concept and a low-resolution prototype of it. (You may use your low-resolution prototype from the project design review or modify it if your leading concept has changed.) Also, draft a BOM and use it to draft a budget for building your leading concept. **Bring these items to lab on 3/23 or 3/24 for Milestone #1.**

(c) Create a rough draft of an FMEA on your leading concept(s). Use it to highlight aspects of your design that would benefit from additional experimentation and/or modeling.

(d) Build a functional prototype of a critical subsystem that would benefit most from experimentation and design iteration. Experiment with the prototype and redesign/adjust it as appropriate. **Bring this prototype to lab on 4/6 or 4/7 for Milestone #2.**

(e) Use the prototype from part (d) or build a functional/experimental prototype of another subsystem that would benefit from experimentation. (Ideally, reuse most of the parts of your experimental prototype for your final prototype, so you do not add to your final budget.) Design and conduct at least one physical experiment to better understand the performance of your prototype. Utilize factorial experiment designs with at least 3 design variables and at least 2 responses. Carefully plan your experimental procedure (setting, equipment, variables, noise factors) to obtain results that are useful for embodying your final design. Use the results to update your design.

(f) Build one or more computer and/or analytical models to simulate important aspects of your design. Use the model to explore different variants of your components (e.g., dimensions, shapes, materials) and to predict their performance. Use the results to update your design.

(g) Based on the results of your experiments and simulations, update your preliminary drawings, bill of materials, and budget to form your preliminary final design. When compiling your budget, think carefully about the replacement parts you might need and the budget for them.
(h) Apply Design for Manufacturing and/or Design for Assembly guidelines and analysis to your product to identify ways to make it easier to assemble and repair. Keep in mind the DIY fabrication instructions you will generate in item (n).
(i) Perform a basic sustainability analysis of your preliminary final design. Identify at least two design decisions that enhance the sustainability of your device and at least two design decisions that currently detract from the sustainability of your device, assuming that the device is to be transitioned into a DIY kit.
(j) Update your FMEA to document any changes you have made to your design.
(k) Build prototypes of each of the remaining subsystems of your preliminary final design. Build these subsystems with the intention of integrating them into a fully functioning system for the design showcase. **Bring your subsystem prototypes to lab on 4/20 or 4/21 for Milestone #3.**
(l) Update your preliminary final design based on the results of the FMEA, the Design for Manufacturing and Assembly analysis, the sustainability analysis, and the subsystem prototyping. The result is your final design, which should be documented with CAD models of the parts you fabricate yourself, a complete bill-of-materials, a final budget, and either a CAD model or neat well-proportioned hand drawings of the complete assembly with isometric, side, front, and top views. The drawings can be either CAD models or hand drawings, but they should be sufficiently developed so that an engineer can begin drafting CAD models for production.
(m) Assemble and integrate a fully functional prototype of your final design for the showcase in the week of April 29.
(n) Prepare assembly instructions for a DIY enthusiast to build your equipment, assuming that the enthusiast has access to your off-the-shelf components and a maker space equipped similarly to the Texas Inventionworks. The assembly instructions should be included as an appendix to your final report.
(o) **Writing Tips:** Your final report should describe the entire design process (from problem statement to the evaluation of the final prototype). Start with your design proposal and design review documents and merge them with the text for this phase of the design project. Limit the text in the compiled report to a maximum of 45 pages with standard 1-inch margins, double line spacing, and 11 point font. Revisit your writing TA's comments on the design proposal and design review and edit those documents before merging them into the final report. Pay particular attention to writing quality and follow your writing TA's tips because overall writing quality will constitute 20% of your final report grade.

4. Final Presentation (Due: In Lecture from April 29 – May 4)

Prepare a final presentation of your project. Grading criteria, time limits, and scheduling will be provided in class. The current plan is to host the final presentations during lecture time.

5. Final Design Showcase (Due: In Lab the week of April 29 – May 4)

Prepare your prototype to perform the mission described on pages 1 and 2. The current plan is to host the showcase during lab times.