Robotics For Healthcare

Design and Concept of an Autonomous Feeding Robot

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DESIGN FRAMEWORK

- **Why** design this robot?
- **Who** makes it?
- **How** do we make it?
- **Who** will use it?
- **What** do we make?

DESIGN FRAMEWORK

Why design this robot?

Who makes it?

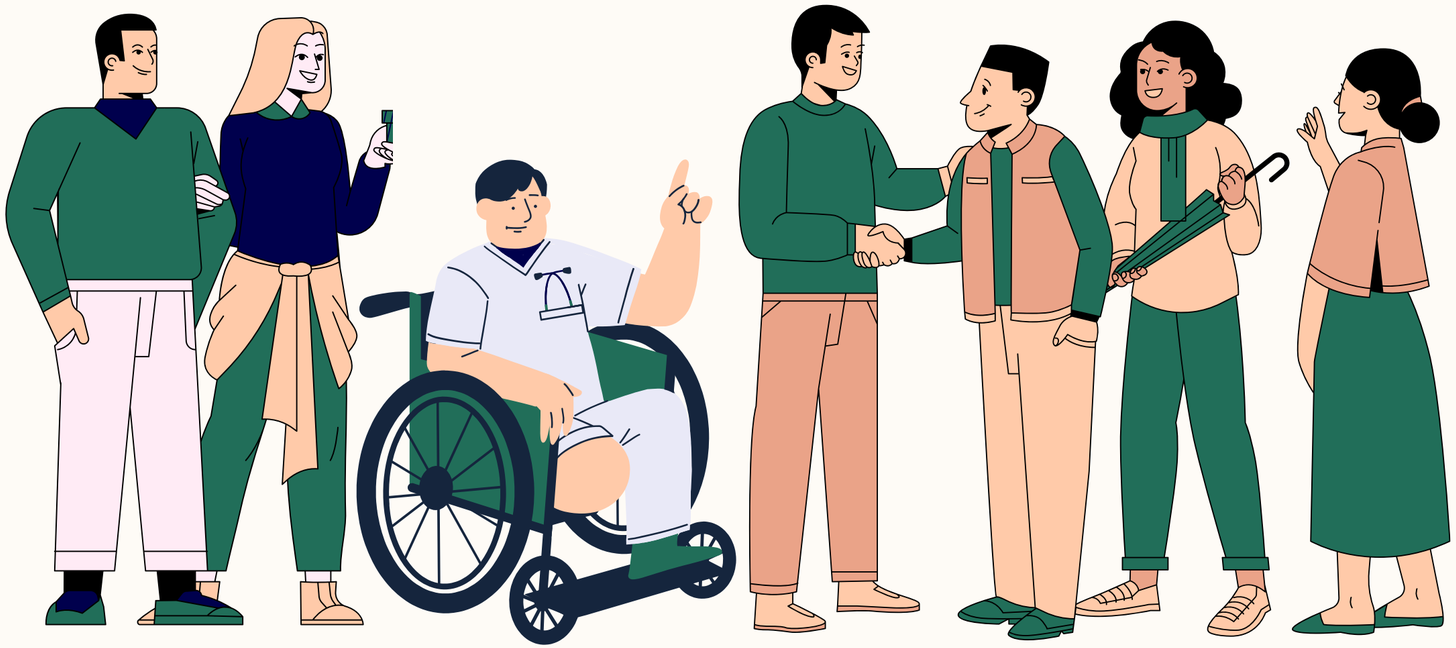
How do we design it?

Who is the robot for?

What do we make?

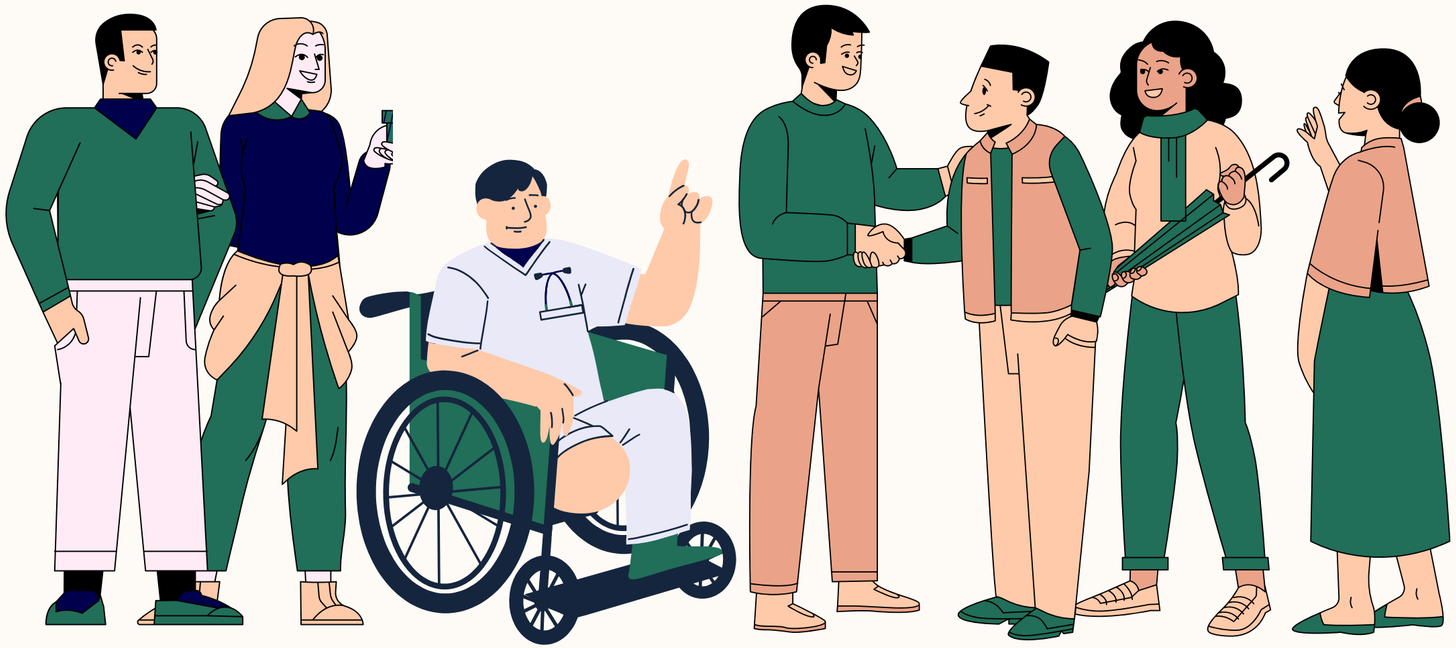
15% OF THE WORLD'S POPULATION = **1 IN 7 PEOPLE**

experience a **disability**



3.8% OF THE WORLD'S POPULATION = **1.9 MIL PEOPLE**

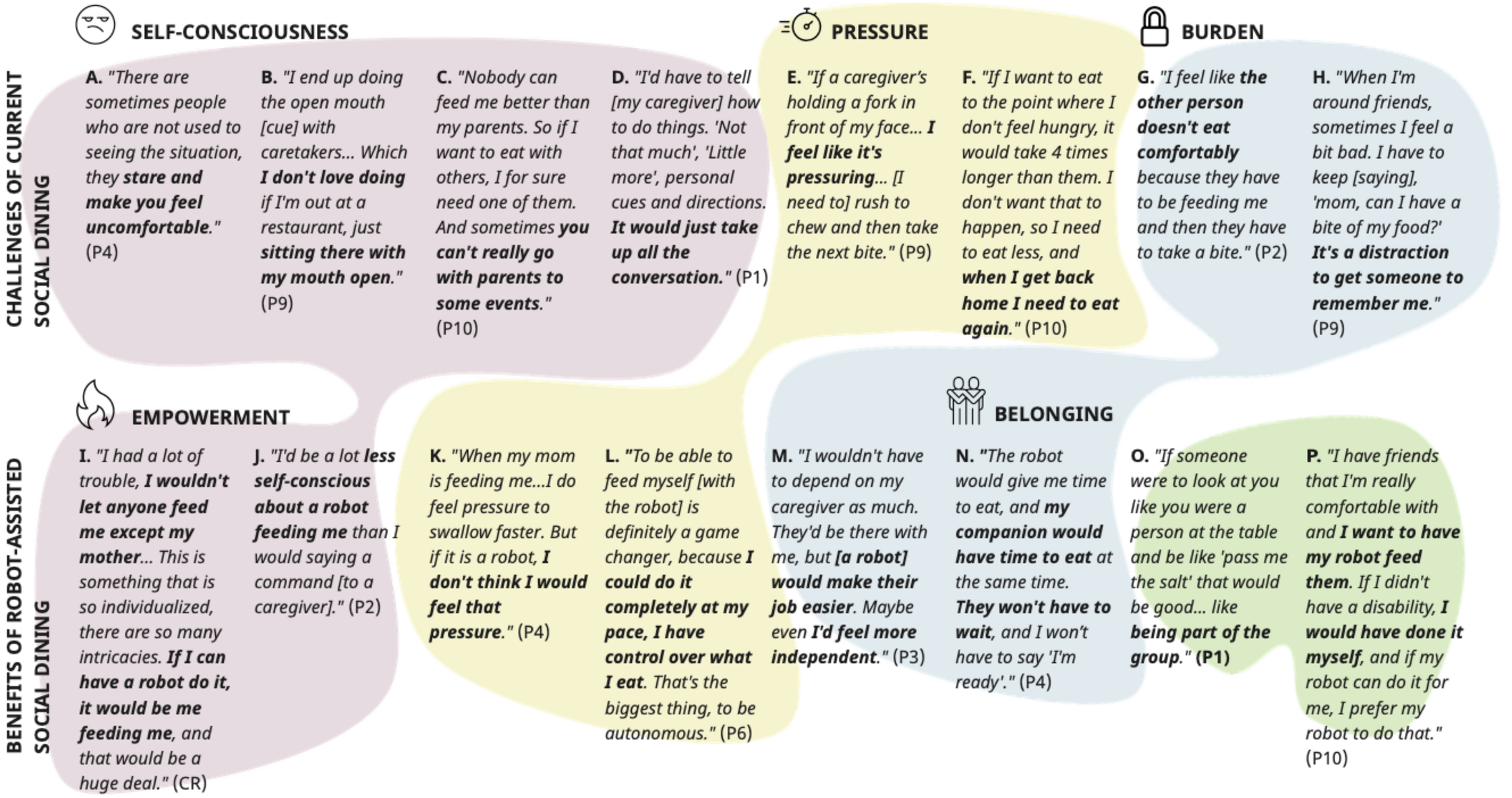
have difficulties to perform **ADL**s



Background

People that lives with disability or disease affecting their upper extremities face various difficulties to perform activity of daily activities such as dressing, hygiene, eating and communication.

Assistive Devices and Manipulation Aids are made available to increase the individual's independence and confidence in performing the a task, and facilitate re-integration in the society.



Nanavati, Amal & Alves-Oliveira, Patrícia & Schrenk, Tyler & Gordon, Ethan & Cakmak, Maya & Srinivasa, Siddhartha. (2023). Design Principles for Robot-Assisted Feeding in Social Contexts. 24-33. 10.1145/3568162.3576988.

Our Clinical Problem

To Assist Individuals with Upper Extremity Disabilities with Feeding

Stroke patients,
tetraplegia or quadriplegia

Limited motor abilities including
range of motion and/or strength

DESIGN FRAMEWORK

Why design a feeding robot?

Motivation

- Promote User Independence
- Among the ADLs, feeding is the most important activity to maintain life

Who is the robot for?

What do we make?

DESIGN FRAMEWORK

Why design a feeding robot?

Motivation

- Promote User Independence
- Among the ADLs, feeding is the most important activity to maintain life

Who is the robot for?

Target Users

- Users with permanent motor impairments who rely on a caregiver to be fed

What do we make?

What do we make?

User Preferences

Bite Initiation

- Prefer switch based, open mouth or voice-based
- Customisable bite initiation

Bite Transfer

- Spill-free bite transfer
- Invariance to user position
- Unobtrusive bite transfer

Safety

- Emergency stop
- Compliance

Food Acquisition

- User-specified bite size
- Diverse and size-agnostic bite acquisition

Bite Selection

- Multiple food selection
- Cancel approach on request
- Drinking Mechanism

DESIGN PRINCIPLES

Customisation

The robot should be adaptable to contexts and user needs

Ease of Use

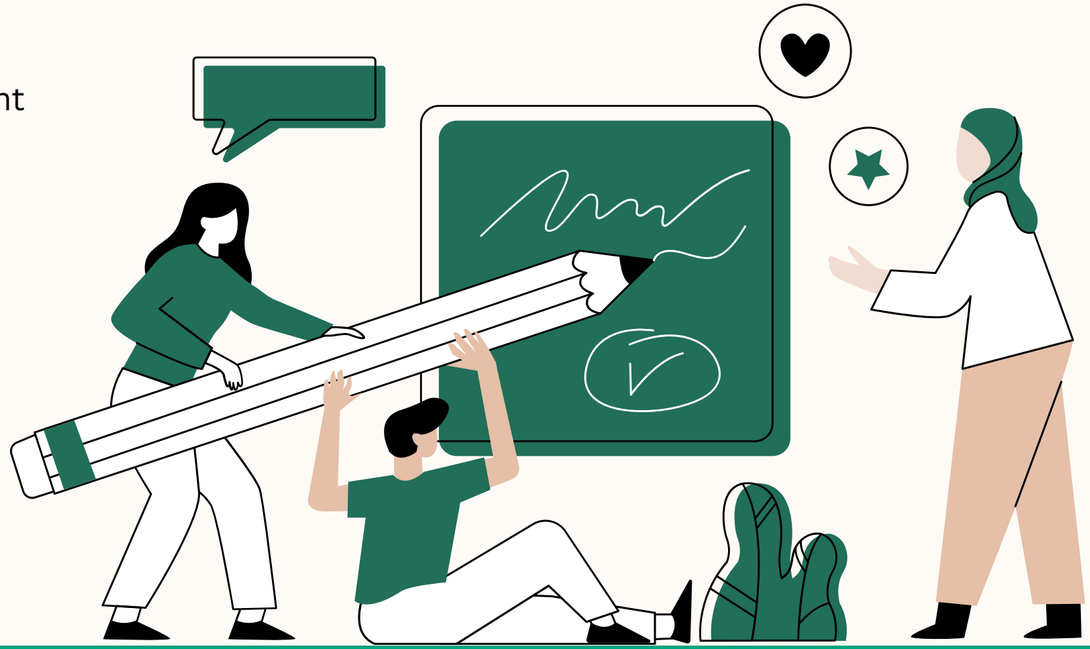
The robot should be intuitive for the users and limits involvement of caregiver

Safety

The robot should be consistent and error-free

Control

The robot should defer high-level decision making to the user



Portable

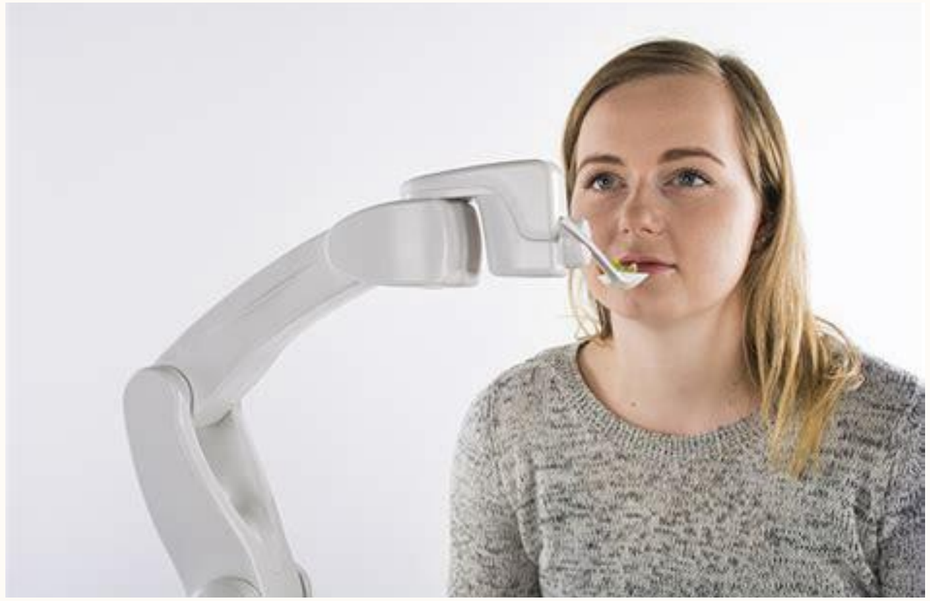
The robot should be compact and easy to setup in a new environment

Inclusivity

The robot should accomodate user’s impairments

Existing Design Review

OBI : Meal Assistance Robot



https://meetobi.com/meet-obi/

OBI

+ Customisation	Hand-guided Teach Mode that can deliver food to the front of the user's mouth in a position that is most comfortable for the user
+ Control	User is able to choose between 2 different spoon attachments and select from 4 food compartments
+ Ease of Use	Customisable switch to match user preference Spoons and plates are dishwasher friendly and easy to clean for the caregiver
+ Portability	Battery-powered, light and compact design
+ Safety	Collision Detection

OBI

- Customisation

Limited bite initiation, the only option is mechanical switch
Limited food options due to scooping with a push mechanism

- Ease of Use

Caregiver has to teach the appropriate food delivery location in front of the user's mouth every time the user position change

- Inclusivity

User has to maintain a sufficient upright position and head control to receive food
User has to have the strength and dexterity to control a mechanical switch

- Portability

No locking mechanism of robot arms when not in use, to prevent the increase risk of damage, robot needs to be place in original box during travel

- Safety

No emergency stop button

Drawbacks to Address

- Limited bite initiation with control switch
- User has to maintain a sufficient upright position and head control to receive food
- Limited food options due to scooping with a push mechanism and no drinking mechanism
- No locking mechanism and no emergency button

Our Objective

- More intuitive and customizable user control for better eating experience
- Improved bite transfer to allow feeding food into the user’s mouth
- Mechanism to improve food acquisition and more versatile attachments
- Design a locking mechanism to secure robot arms and improve safety

Cost Justification & Constraints

High Cost of Assistive Devices

Feeding robot is considered a high-tech device with a specific intended application. Although the goal is to make a commercially available assistive device, those cost are still relatively high.

OBI Cost ~ 6000 USD

Improve the user and families' quality of life

Feeding takes place 3 times a day, having a feeding robot to replace the caregiver can significantly alleviate the burden users have on the caregiver and allows more time for caregivers to perform other tasks.

Hiring a Caregiver is expensive

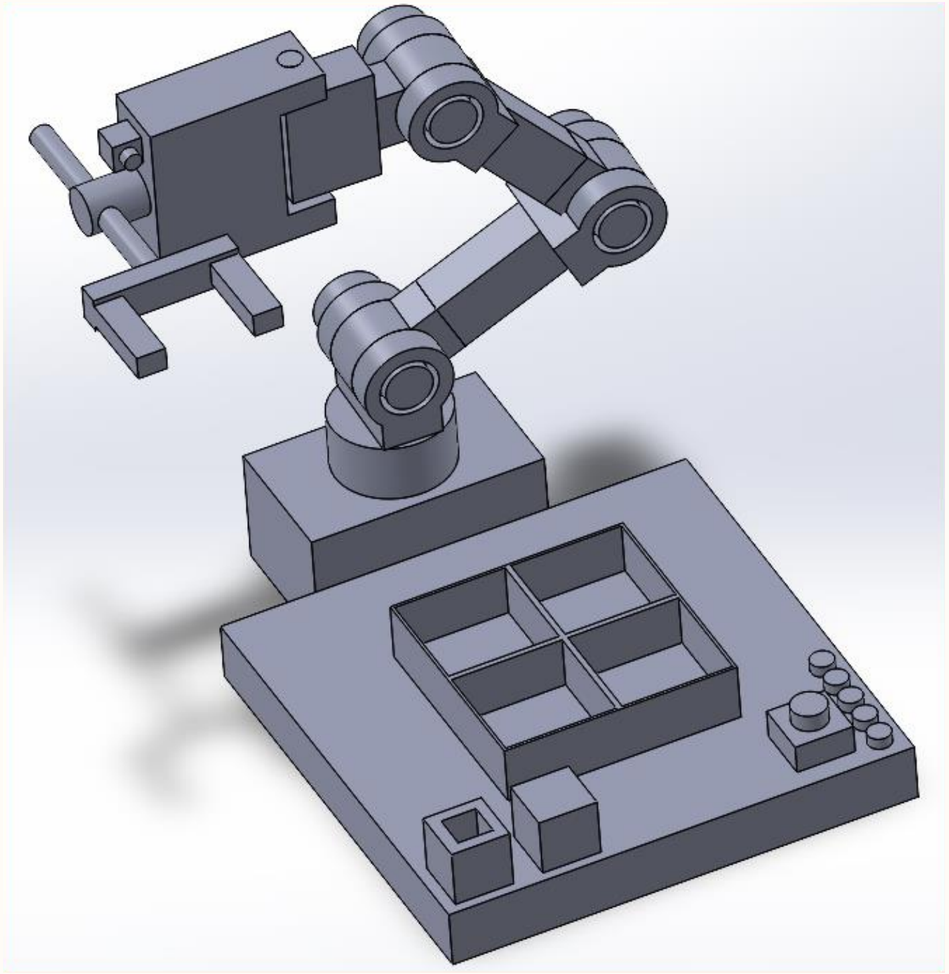
According to *caringcaregiver.sg* the cost of hiring a caregiver can be represented as

Levy ~ 300 SGD
Salary ~ 580 SGD
Groceries & Transport ~ 160 SGD

Reduce Labour in Institutes

In places like orphanages, old folk home or care facilities, 1 caregiver is required to feed 1 user at a time, with this caregivers only need to take care of food preparation, and the feeding can be done independently by the users

Our Design



Home Pose View

Robot Arm Configuration

User Preferences

Bite Intiation

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Bite Initiation Considerations

More intuitive and customisable user control for better eating experience

Mechanical Switch

+ **Tactile Feedback** : Allows users to feel when they have successfully input a command
+ **Reliable** : Physical buttons are less prone to technical issues
+ **Subtle** : User feedback that the button is subtle
- **Limited Customisation** : Limited capacity adapting to specific user preferences
- **Dependency on Physical Dexterity** : Some users have difficulty with fine motor skills

Open Mouth Recognition by Camera

+ **Intuitive** : Aligns with how users currently interact with the caregiver
- **Light sensitivity** : Face detection system may fail in low light condition
- **Prone to Misinterpretation** : Robot might misinterpret user talking as a signal to start feeding
- **Awkward** : Users may feel awkward opening their mouth in a social setting

Bite Initiation Considerations

More intuitive and customisable user control for better eating experience

Voice Recognition

+ **Hands-free Control** : Beneficial for users with limited mobility or dexterity
+ **Natural Interaction** : Voice commands can provide a more natural and intuitive way of controlling a robot
- **Noise Sensitivity** : Voice recognition systems may not be reliable in noisy environments
- **Require Good Speech Articulation** : Not accessible for users who have speech impediments

Automatic

+ **Hands-free Control** : Beneficial for users with limited mobility or dexterity
- **Loss of Control** : Undesireable for most user with cognitive and physical ability to control the robot

Our Design | Bite Initiation

More intuitive and customisable user control for better eating experience

Provide user with the option of mechanical switch and voice recognition depending on the context

Mechanical switch design with 5 buttons

Functionality

- One for each food compartments (4 buttons = 4 compartments/slots)
  - Press to select desired compartment for feeding
  - Single press initiates feeding action for the selected compartment
  - Second press cancels operation, bring back food to compartment and returns the robot to home position
- Multi-purpose home button (1 button)
  - Press to enable voice recognition
  - Press and hold to reset arm to home position

Advantages

- Intuitive design for easy compartment selection
- Quick cancellation option prevents unintended actions
- Enhances user control and robot responsiveness
- User-friendly interface prioritizes safety and ease of use

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Our Design | Bite Transfer

Improve bite transfer to allow feeding food into the user's mouth

Load sensors at the end effector measure feeding forces, coupled with stereo cameras for vision, ensuring precise and successful food transfer in the autonomous feeding process.

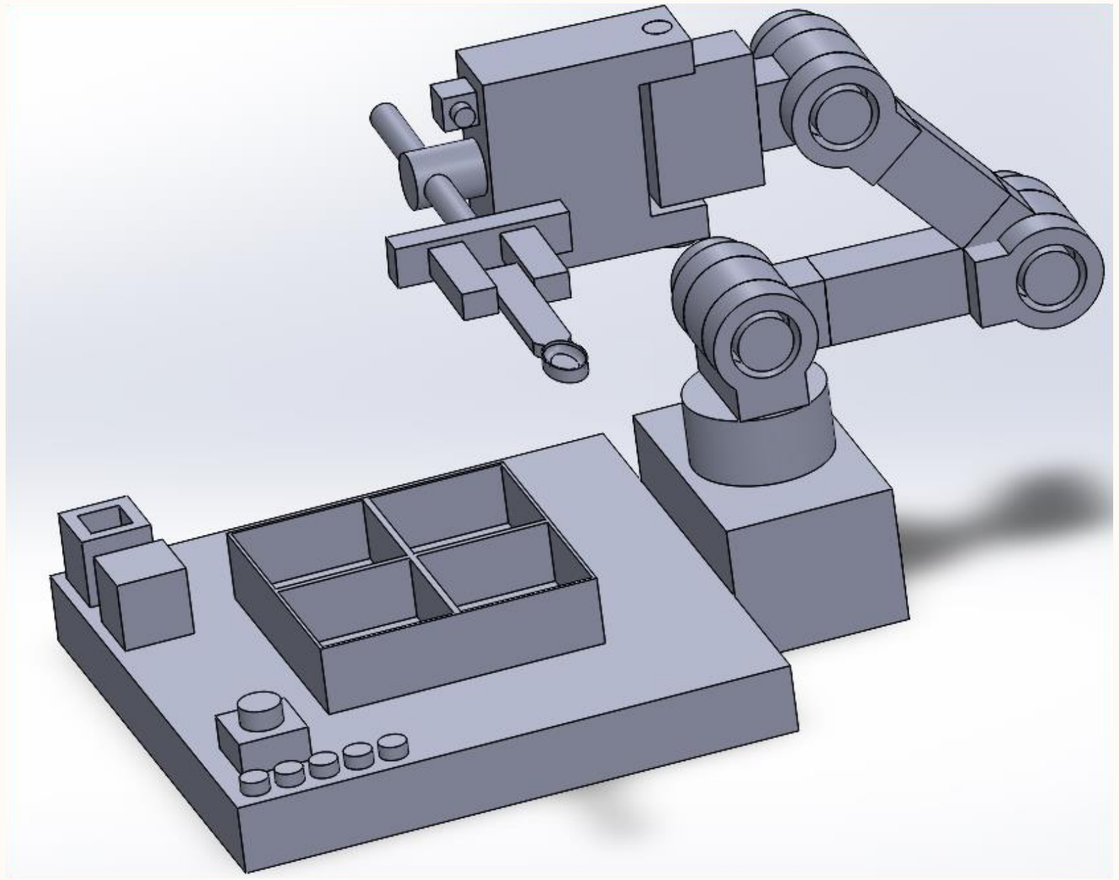
Load Sensors:

- Force Signatures:
  - Establish a baseline force signature for a successful transfer of food
  - Analyze the real-time force readings during the feeding process
- Force Patterns:
  - Define specific force patterns associated with the successful delivery of food
  - Program the robot to recognize these patterns during the feeding operation
- Thresholds and Tolerance:
  - Set force thresholds that indicate successful food transfer

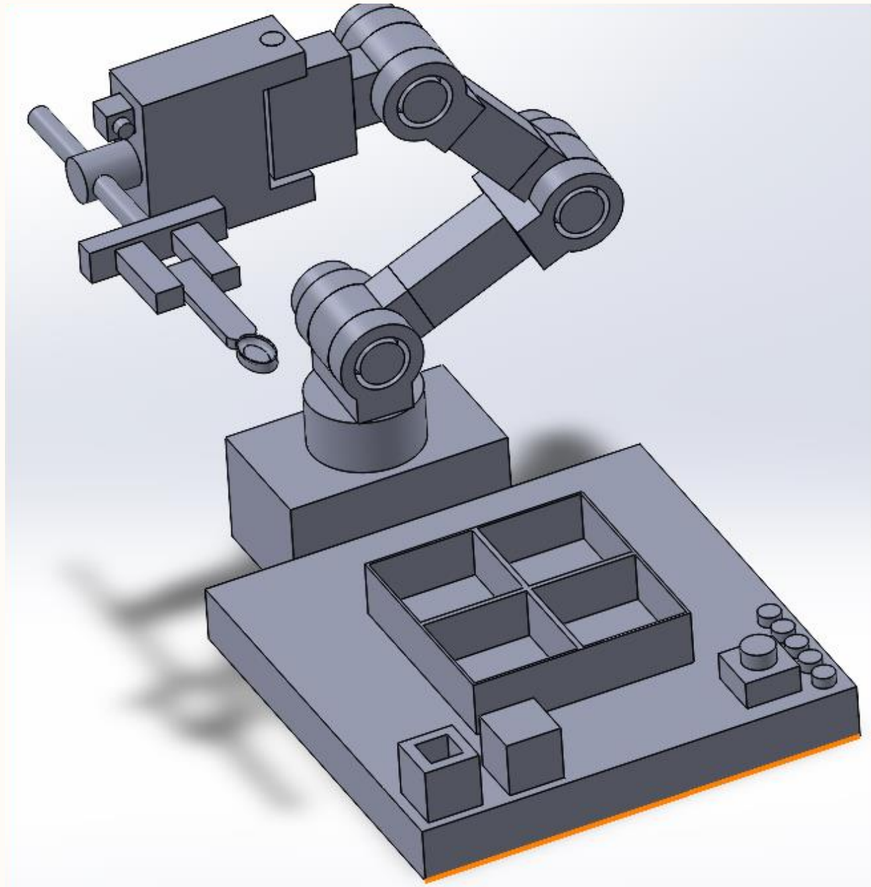
Stereo Camera:

- Stereo cameras contribute to enhanced vision and depth perception
- Aid in accurately positioning the end effector for precise and safe feeding actions

Our Design



Bringing the portion to the user



Neutral Configuration

Robot Arm Grip Spoon

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Our Design | Safety

Design a locking mechanism to secure robot arms and improve safety

Locking Mechanism

- Integrating mechanical brakes at each joint enhances safety, preventing unintended movements and minimizing the risk of damage during transit in our robot arm design

Physical Design

- Use light weight materials for joints and arm links
  - Aluminum alloys strike the ideal balance between lightness and cost-effectiveness
- Soft padding on the end effector and a specially designed gripper enhance safety, preventing injuries during accidental contact
  - Soft materials like silicone or rubber are suitable for applications where gentle contact is required
- Force/Torque sensors placed at joints of the manipulator to enhance compliance, ensuring safety in human-robot interaction

Emergency stop button

- Although equipped with collision detection technology, users express that they feel more comfortable with having an emergency as a fail safe

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Our Design | Food Acquisition & Bite Selection

Mechanism to improve food acquisition while using the spoon attachment

Probe-then-scoop approach

Bringing the spoon in contact with the food surface without actually scooping to obtain visuo-haptic information about the food item.

With the assistance of stereo camera for vision assistance, and pre trained network to detect the food items, these readings allows for recognition of texture and type of food to optimise food acquisition, broadening the food options that can be offered to the users.

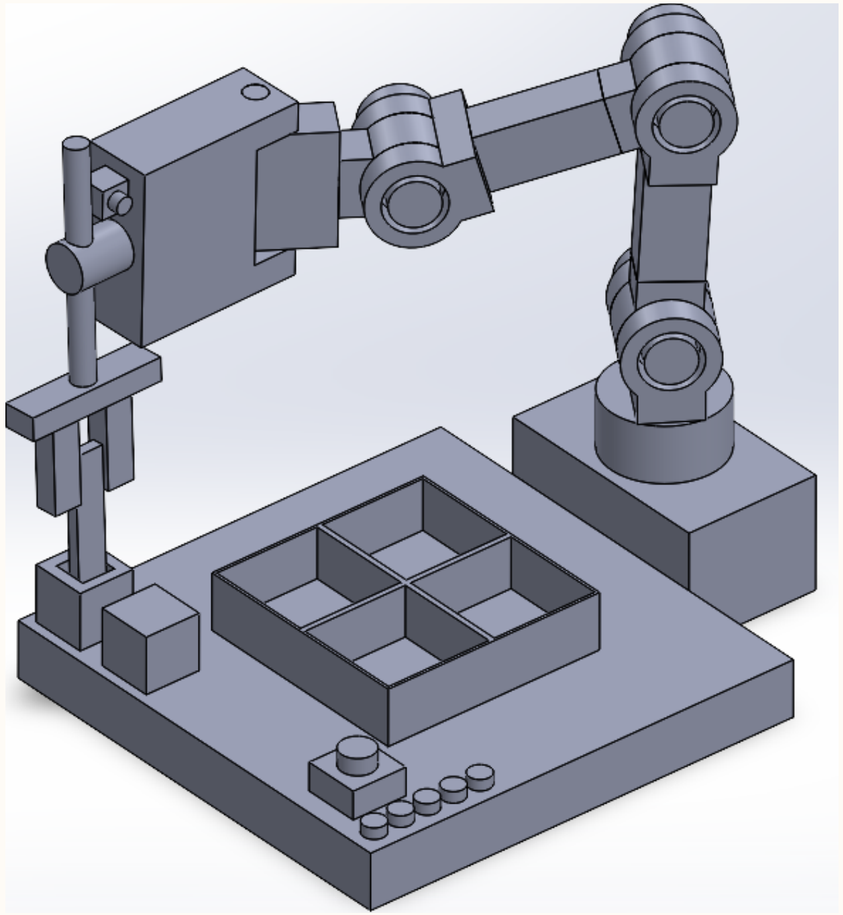
Gripper End-Effector

Design a gripper end effector to provide option to grip a glass of water and grip utensil attachments.

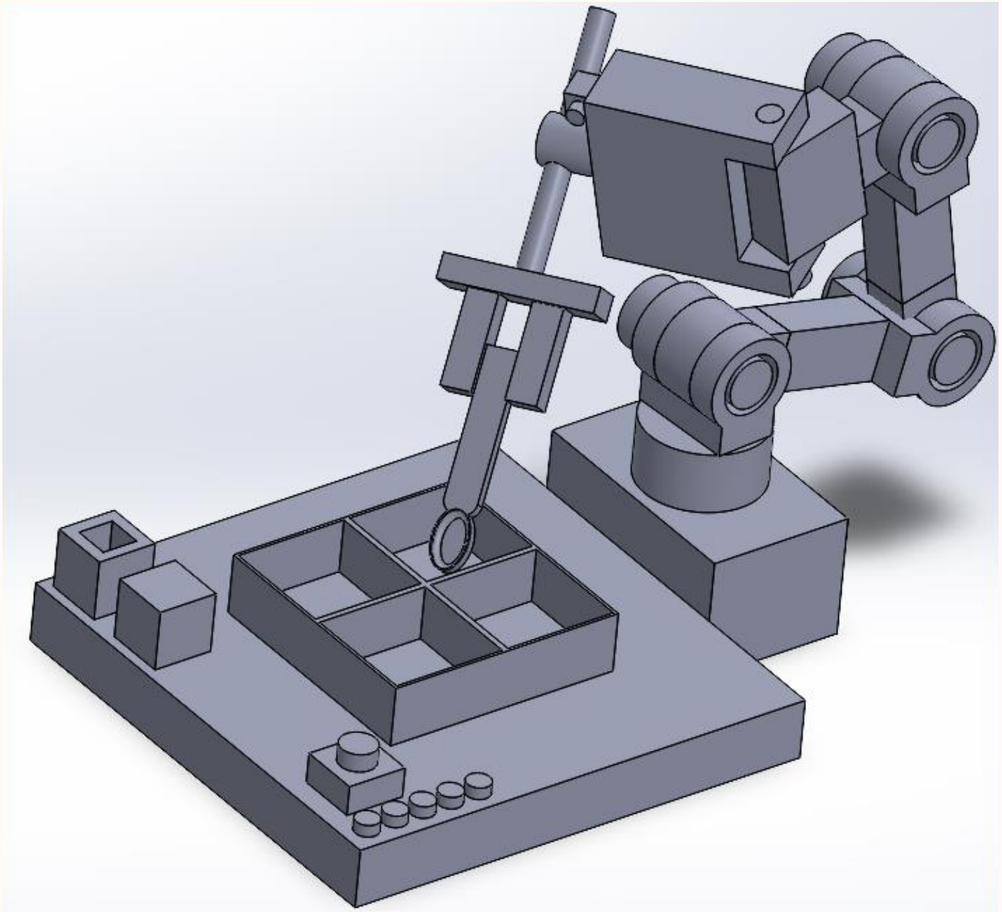
- Special utensil attachments provided with the robot

Sundaresan, P., Belkhale, S., & Sadigh, D. (2022). Learning Visuo-Haptic Skewering Strategies for Robot-Assisted Feeding. ArXiv, abs/2211.14648.

Our Design



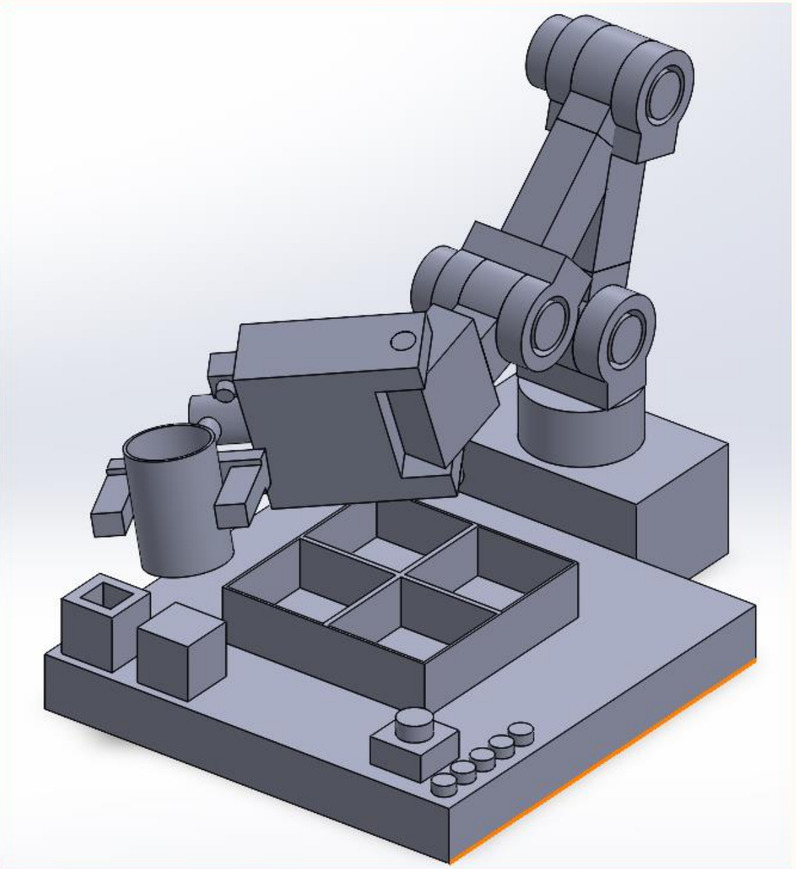
Grip a spoon



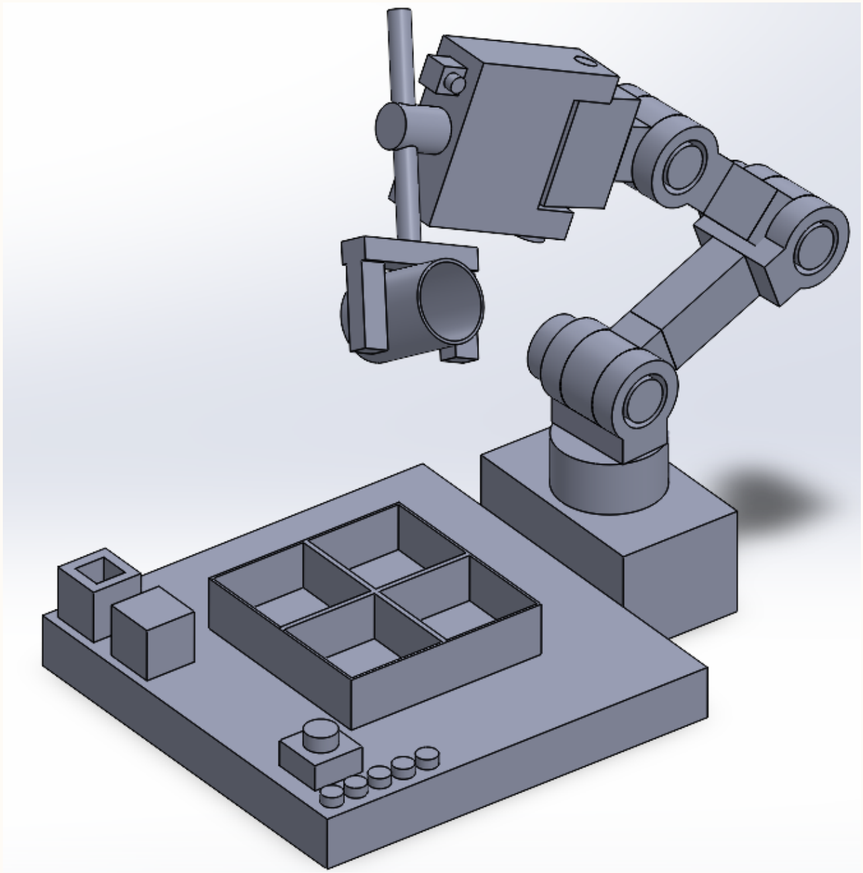
Scooping up a portion

Robot Arm Grip Spoon

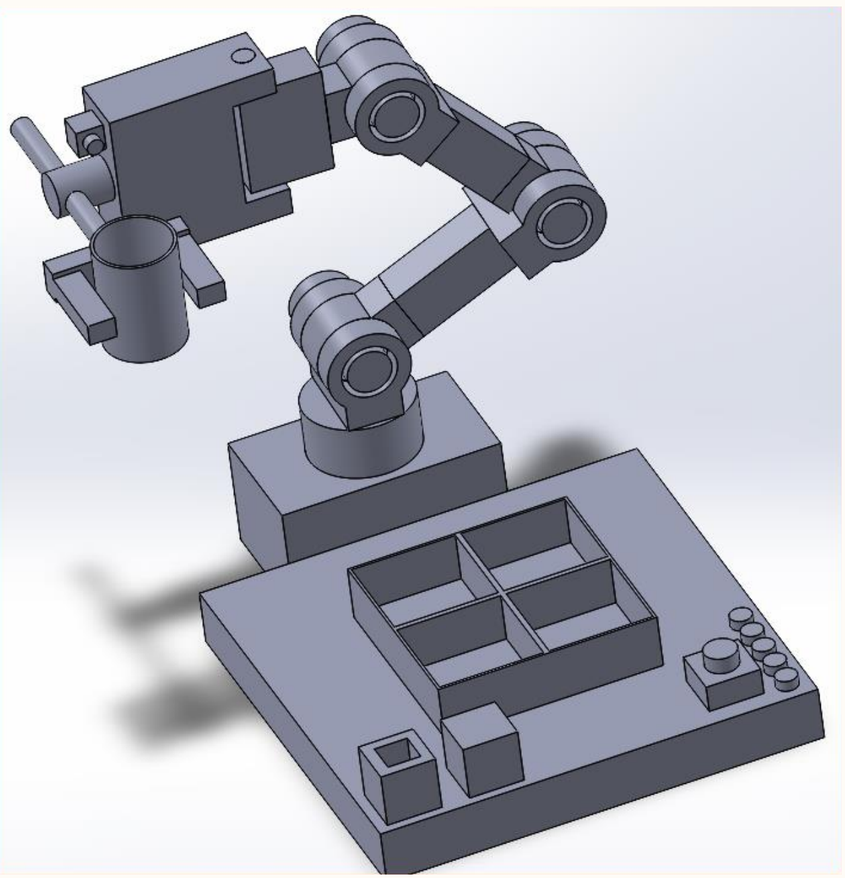
Our Design



Grip a cup



Bringing the cup to the user



Neutral Configuration

Robot Arm Grip Cup

Control System

Planning Algorithms with a Model Predictive Controller

- Ensure that the feeder orchestrates an **optimal and secure trajectory** to the user’s mouth.

Sophisticated Kinematic Model

- Enables **precise positioning and movement control**.

Comprehensive Dynamics Model

- Precisely governs the **end effector force and joint torques**.

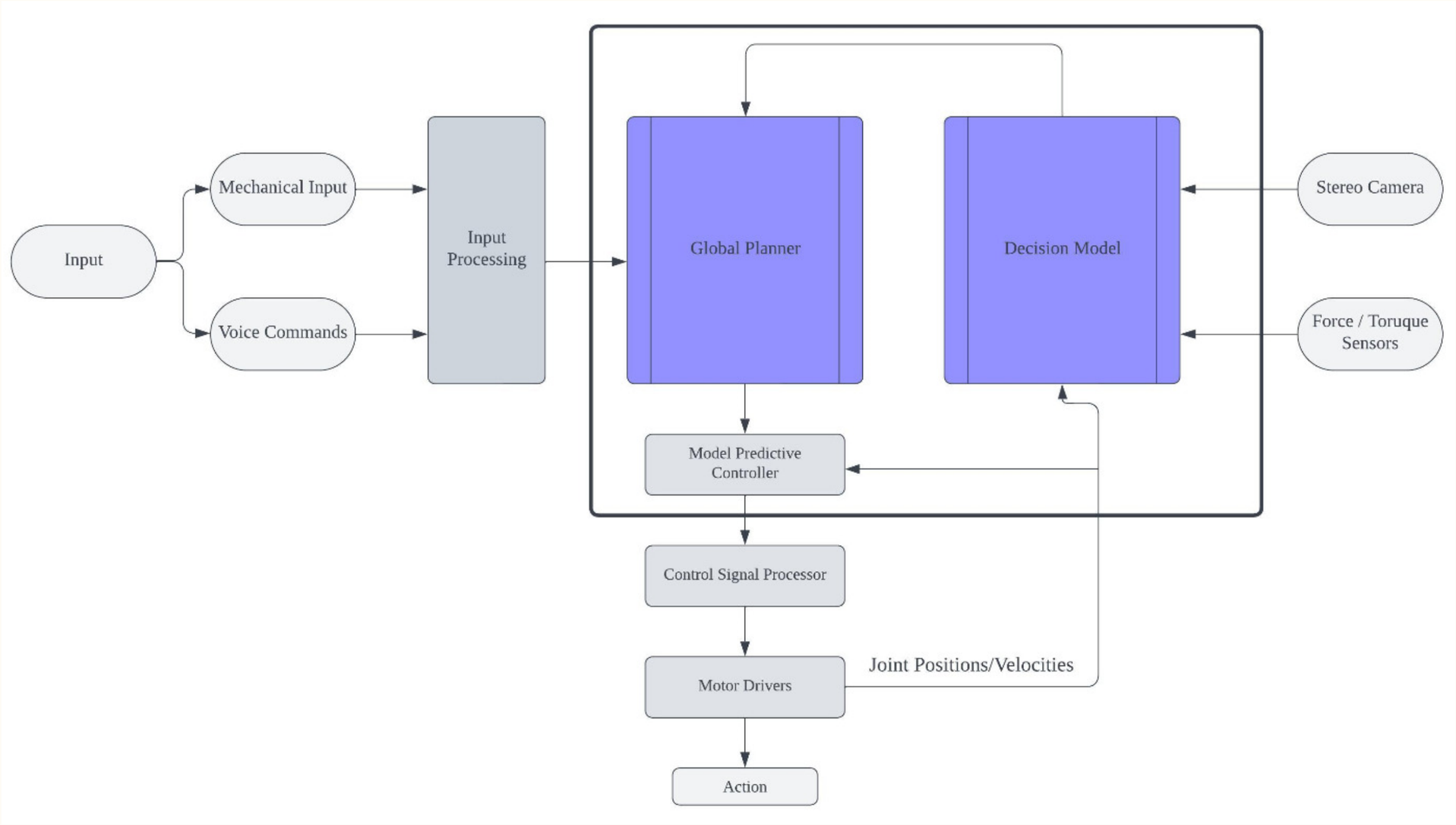
Control Algorithms

- Limit the force exerted by the manipulator, **preventing harm to the user or damage to objects**.

Integration of Machine Learning and Computer Vision

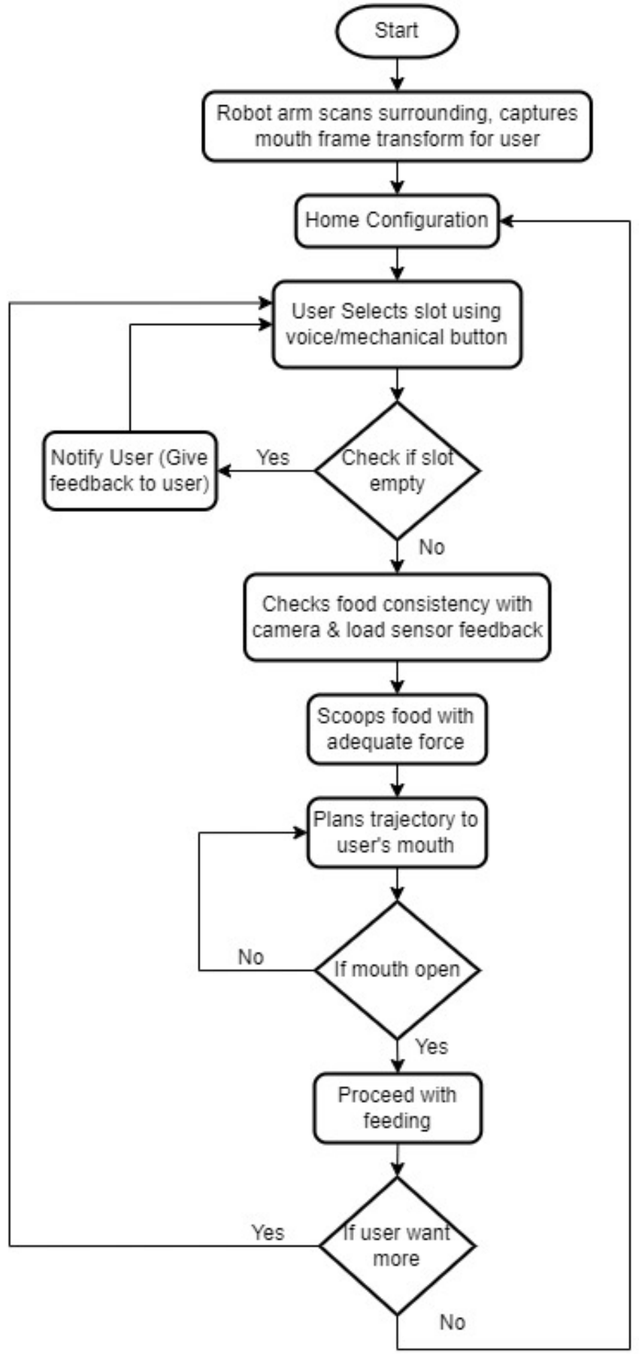
- Enhances the system's capabilities, allowing for **effective object recognition and manipulation**.
- This holistic approach ensures both **efficiency and safety** in the robot's interactions with its environment and the user.

Control System



Robot Operation

How it works



Conclusion

- **More intuitive and customisable user control** for better eating experience can be achieved by providing options of **mechanical switch buttons and voice command based on the user preferences**.

- **Improved bite transfer** using a **load sensor to measure feeding force** and a **stereo camera to position the end effector** accurately to allow feeding food into the user's mouth.

- **Integrate a mechanical break system** in each joint of the robot arms to **secure robot arms and improve safety**.

- **Probe-then-scoop approach** used as a mechanism to **improve food acquisition** and **Design of gripper on the end effector** to provide a **more versatile utensil attachment** (spoon, cup, etc.)

Thank you.