**Motivation**

- Object recognition algorithms often fail to recognize target objects even when they are in the viewable region of the environment due to distance, lighting and resolution effects because they change the appearance of the target objects.
- Mobile manipulators are more flexible under a number of possible combinations of algorithms, sensors, viewpoints, and environmental conditions because they can actively change sensor and environmental geometry, interact with objects, change illumination, and change feature extraction algorithms to gain more information about the target object.

**Research Question & Hypothesis**

**Research Question:**
- How can the mobile manipulator find target objects effectively and efficiently?

**Hypothesis:**
- The mobile manipulator must select appropriate perceptual operators, control viewing angles, manipulate objects to manage perceptual complexity and ambiguity given different object types, costs of actions, and environmental conditions.

**Problem Formulation**

- We consider a task in which a mobile manipulator searches for a target object in a room.
- The robot must explore the space, compute a path, detect object candidates, and verify that the detected object is a target object.
- Informative actions include changing a pose, selecting an object to investigate, controlling environmental conditions such as the distance to the object and illumination of the room, and applying a perceptual operator.
- Perceptual operators extract visual 2D features such as hue-saturation and SIFT [1], and 3D visual features such as the size of the object and PFH [2]. We utilize the decision making algorithm proposed by Marengoni [3] to decide on the next action.
- The system computes the value of information for each action by computing the difference between the current utility and the expected utility per unit cost as shown in Equation (1).

\[ \text{Utility} = \frac{\text{expected utility} - \text{current utility}}{\text{cost of action}} \]

**Experiment**

- Task: Find a target object.
- Environment: Simulated indoor environment in V-REP simulator.
- Robot: uBot-6: a small light-weight bimanual mobile manipulator developed at the University of Massachusetts Amherst. An RGBD sensor is mounted on the robot.
- Perceptual Operators: Hue Saturation Histograms + correlation, SIFT (Scale-invariant feature transform) + Bag of Features + SVM, PFH(Point Feature Histograms) + Bag of Features + SVM.
- Motor Operators: Drive to the position NEAR or FAR from the object, Turn on a light switch.
- Trials: 36 trials (18 trials: all lights are always on, 18 trials: all lights are off when the search task begins.)
- Each trial uses a different target object.
- The object locations and the initial position of the robot are the same.
- The robot does not know the locations of objects.
- Evaluation: Compare the proposed algorithm with a random selection algorithm.

  - Effectiveness: The number of actions to take, and success rate.
  - Efficiency: The mean of execution time to recognize each object.

**Results**

- There is a statistically significant difference between the proposed algorithm and the random algorithm.
- The number of times the robot found the correct target object was 75% for the proposed algorithm and 58.3% for the random algorithm.
- The results show that Hue-Saturation and SIFT are fast to compute, while they are not necessarily useful in the dark condition.
- PFH is expensive, but it functions well in most cases. However, if the target’s shape is similar to the other object model, PFH cannot differentiate the target object. In that case, the robot sometimes decides to go to turn on the light even the light switch is far from the robot.

<table>
<thead>
<tr>
<th>Evaluation</th>
<th>P-Value</th>
<th>Proposed</th>
<th>Random</th>
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<tr>
<td>Number of actions</td>
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<td>5.214</td>
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<tr>
<td>Time (sec)</td>
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<td>37.160</td>
<td>58.857</td>
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**Conclusion**

- We introduce an active sensing system to solve the object search problems.
- The preliminary results show that our system finds a target object effectively and efficiently in the simulated environment.
- Our proposed algorithm is general enough to include other perceptual operators such as tactile operators that can sense the weight and the surface texture of the object, and we are working on these operators to extend the system.

**References**