Sustainable Design of a window cleaning robot

Our project designs a robotic system to clean exterior windows of a building, replacing the manual process done by hands. The robotic system consists of a cleaning robot named “Spider Maid” and a mobile crane that operates on the rooftop. The Spider Maid can attach itself on inclined or vertical glass facades of a building using suction cups mounted on tank treads. The tank treads coupled with suction cups allow the robot to maneuver vertically in any direction to reach corners. The cleaning job is performed by two sponge rollers in combination with cleaning liquid sprayed from two cans carried by the robot. The cleaning operation is monitored by two wireless video cameras.

The Spider Maid is tied to a rope that hangs down from a mobile crane running at the same speed on rooftop. The crane also deploys and retrieves the Spider Maid from the rooftop. Furthermore, the crane provides a fail-safe system in a rare incident when the Spider Maid lost grip on surface. Two ultrasonic sensors are mounted on the object hanging side of the crane to ensure it travels at a safe margin away from the edge of building. Safety is a top priority in window cleaning business and we design a fault tolerant system.

The Autodesk Sustainability Workshop raised our awareness that a designer can change a product the way it works that lead to a sustainable world. With understanding the Whole System and Lifecycle Thinking from the Workshop, we identify a way to use resource efficiently by increasing equipment utilization to embrace the concept of “Green building”. Unlike a permanent building maintenance unit that use tracks, our mobile façade cleaning system can be transported to another location easily and can be deployed in minutes. Our sustainable design empowers a single system to clean many buildings. Sharing equipment reduces consumption of non-renewable resources and minimize waste as well as affordable.

In addition, we select biodegradable sponge made of recycled materials and biodegradable, non-toxic cleaning liquid to minimize environmental impact. Suction cups are made of polyurethane. Polyurethane has better abrasion and tear resistance than rubber and make suction cups durable. At the end of life cycle, polyurethane is recycled and re-use. Solaris panel is installed on the crane to recharge the on-board battery.

We started the design process by defining a list of goals and we prioritized them. We brainstormed with design ideas and conducted online research to help us assess the feasibility and limitations of design proposals. We used decision matrix to rate performance for each option based on a list of criteria for decision making. In the second iteration of design cycle, we selected tank tread for its superior traction rather than a simple 6 wheel configuration. We also used decision matrix to compare physical properties, recycled materials, environmental impacts of materials in order to select “green” materials to build the robots.

Worm gear was proposed to lift load in crane because it resists back drive. In the third iteration of design cycle, we did quantitative analysis of gear systems for speed and torque. Calculation showed that the high gear ratio of worm gear (24:1) could not deliver the speed to catch up with the vertical movement of Spider Maid. At the end, we made a tradeoff and build the gearbox with gear ratio 7:1 using two high strength spur gears driven by two motors, one on each side to resist high shock-loads but delivered the necessary speed.

Software

We drew our first sketch on Autodesk SketchBook Mobile in iPad by finger. We found it a challenge to draw straight lines by a finger. We decided to draw designs on notebooks using Autodesk SketchBook Pro. We liked the ‘Layer’ feature which allows us to re-edit our design easily. We also used ‘Symmetry’ feature extensively to draw something the exact opposite on the other side.

In Autodesk Inventor, we used iMates to assign constraints before assembling components to speed up assembly process. We leveraged ‘Pattern’ feature to duplicate tread links to construct tank tread and copied rectangles to create exterior windows of a building. Eco Materials Adviser was used to compare the water consumption and Carbon footprint of Aluminum and Stainless Steel for the chassis. The weight of Spider Maid was estimated by ‘Bill of Materials’. ForceEffect analyzed vector force and helped us to add support beams to the crane structure for reinforcement. Animation was produced by Inventor Studio and image rendering was processed by Autodesk Showcase.