**Max Tech and Beyond Appliance Design Competition Project Description**

**UC Berkeley BEST LAB**

**Professor Alice Agogino**

**Student Leads: Jacob Richards, Aparna Dhinakaran**

Lighting consumes 35% of the electricity in commercial buildings in the U.S. It is very important to ensure that there are energy efficient ways of controlling lighting, in addition to using efficient bulbs. Our inSense system is a combination of light sensors and software that allows for reduced sensing in comparison to current light sensor systems while retaining prediction accuracy. We intend to increase the adoption of smart lighting by making it easier to commission and use sensors, while providing a cost-effective alternative to current systems. The baseline cost of typical light sensor systems, most of which have a sensor at every light fixture is $8.35 per square meter. Our system enables full space coverage for $4 per square meter. This is a 50% cost reduction on market available systems. This also contributes to a reduction of 0.2 to 0.25 quads BTU per year on light energy savings nationwide. We plan to target commercial businesses, as commercial businesses consume 71% of all lighting energy in the United States. Our system uses predictive models to reduce the number of sensors, therefore reducing sensing costs. These models can also provide feedback on the architectural design of a building, which can allow informed decisions about where to place workspaces. This promotes maximum daylight autonomy.

At UC Berkeley in 2008, a team developed one of the first wireless sensor and actuator-enabled intelligent lighting systems. It controls individual luminaires to optimize light levels in a room based on user preferences and energy savings objectives. Similar products have been commercialized since then, but intelligent lighting systems still suffer from a few shortcomings. The decision of where to install sensors in a room is not well defined. Actuation of lights is not robust to faulty sensors and gaps in data in most current systems, and wiring consumes most of the time during commissioning for partially-wired sensor networks. As a result of these shortcomings, 70% of commercial buildings in the US lack smart lighting systems. Of the 30% that do, 50% are suboptimal. inSense patches these holes in the existing systems with robust probabilistic models of individual buildings that aid in sensor placement, prediction of sensor data through virtual sensing, and painless commissioning.

Our technology is composed of two parts: a hardware sensor network component and an optimization software component. In the hardware component, a network of wireless light sensors send data via a multi-hop network to a local server, located on each floor of a building, which carries out computations for light level predictions and optimal sensor placement. The local server communicates with a web client that carries out actuation via wireless dimming ballasts embedded in each light. Our system encompasses the sensing and prediction components of a full lighting system.

The software component of our system works in three stages: a calibration phase, an optimal sensor placement phase, and an operation phase. In the calibration phase, the wireless sensors are deployed at many points of interest in a building, including desks, ceilings and windows. During the next two weeks, the local server builds a probabilistic inverse model from the light sensors data. With this model, we can predict the light level at any point in a room within error bounds at any time. After the two week calibration phase, the local server computes an optimal sensor placement that places a subset of the sensors in the room to minimize prediction error while simultaneously accounting for a company’s budget. The budget dictates how many sensors we choose for the final placement. After the optimal subset of sensors are placed, the operation phase begins. Here, we can predict the light level at any point in the building with the inverse model, and this prediction gives way to intelligent actuation of lights that maximizes usage of ambient light, thereby increasing daylight autonomy. Using the distribution of light for areas of a square meter, we can compute daylight autonomy, a major component of LEED green building certification.

Our technology is energy and cost efficient due to the virtual sensing, which minimizes the number of sensors installed and used. In comparison to Enlighted, Inc, which uses one sensor for every light fixture and has expensive wireless components, our system optimizes the number and placement of sensors for a building’s architecture and a company’s energy and cost budget. Our sensor technology is half the cost of Enlighted’s sensor technology, the current best in the field of smart lighting sensor technology. We have also compared our technology to that of NEXT Lighting, which offers a full sensor and lighting system but is more focused on efficient lighting. As a partner with NEXT, we would extend the capabilities of their sensor systems through our robust probabilistic models, and would make NEXT Lighting’s efficient LED lights coupled with sensors more affordable, because our model allows for a reduced number of sensors.

In order to test the efficacy of our models, we utilized two different testbeds. One is a quarter scale mockup of an office building located in our lab with 4 light sensors, pictured on the right, and the other is a real office space at NASA Ames Sustainability research base, pictured on the right with 4 of the 9 sensors there in red.

Here, we will discuss the results of our probabilistic models at the BEST Lab testbed. We trained our models on the data received by the full set of deployed sensors, and used an optimally-placed subset of the sensors to predict unknown reading values with the model. At the BEST Lab testbed, we achieved 75-95% accuracy when predicting the readings of the other sensors with 1 of the sensors. These accuracy levels demonstrate that it is cost efficient and accurate to use virtual sensing as a component of a wireless smart lighting system.

Using the inSense system alongside a wireless light actuator network could greatly increase the cost effectiveness and reliability of current smart lighting systems. We have demonstrated that our system can retain virtual sensor accuracy while using a smaller number of sensors than other available systems, effectively reducing energy costs by 50%. In a commercial building, this amounts to $5.20 per meter squared. In terms of installation cost, we are minimizing the number of sensors by only having sensors at the windows in the final stage, with possibly a few other sensors deployed in the workplane, which amounts to an 84% savings over systems that have sensors at every light fixture. We project that there will be a resultant nationwide energy savings of 60,000 gigawatt-hours a year if just 10% of the buildings without smart lighting are retrofitted. Thus, the inSense system will likely increase adoption of smart lighting systems nationwide, due to its low cost and high energy savings.