Optimized Selection and Placement of Sensors using Building Information Models (BIM)

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Abstract: The performance of an advanced lighting system is heavily influenced by the placement and orientation of occupancy sensors and photo-sensors. Incorrect sensor placement can compromise system performance, cause discomfort to occupants and diminish savings. The current process of manually selecting sensors and placing them on a floor plan in a design tool is not only suboptimal but also is tedious and error-prone. To overcome these issues, we have developed a Revit plug-in which automatically deploys sensors on optimal locations in Building Information Models (BIM).

Introduction
Lighting and HVAC accounted for 60% of the energy used in US commercial buildings in 2010 [1]. Lighting controls and Building Automation Systems are proven methods for improving operational efficiency and occupant comfort [2]. The performance of these systems is heavily influenced by the placement of sensors such as occupancy, photo, temperature, humidity, smoke and CO2 sensors. Incorrect sensor placement can compromise performance, cause discomfort to the occupants and diminish savings. For example, placing PIR-based occupancy sensors close to HVAC exhausts can lead to false positive triggers thereby diminishing savings. If an occupancy sensor’s detection region continues beyond doors (or windows) then it can cause unwanted triggers leading to energy waste. If an occupancy sensor’s line of sight to an occupant is blocked by partitions, then lights may turn-off while occupant is present thereby causing discomfort to the occupant. If the photo-sensor is installed near the window then reflections from outside can cause over-dimming thereby compromising occupant comfort. This research is aimed at developing automatic sensor selection and placement methods based on building geometry and characteristics coming from BIMs.

Current State of the Art
Typically, an electrical contractor specifies sensor locations on 2D layout drawings. In many cases, the contractor requests a sensor placement service from a lighting controls supplier. A typical sensing device used in lighting applications may have a photo-sensor and a motion-sensor placed inside one physical enclosure. The placement of such a device has to comply with guidelines for placing both types of sensors. Currently, sensor placement on the building layout is done manually as follows:
1. The engineer manually evaluates space characteristics such as size and function (e.g., office, conference room, etc.), and locations of walls, doors, windows, luminaires and HVAC vents.
2. The engineer identifies a suitable sensor for a given space type and manually calculates the coverage area based on ceiling height, walls and partitions in the chosen area.
3. The engineer studies the manufacturer’s guidelines for sensor placement from sensor data sheets (e.g., do not place the PIR sensor within 2 meter radius of HVAC exhausts; do not place the photo-sensors within 0.75 times ceiling height (Fig. 1)).
4. The engineer reviews the code requirements (e.g. CA Title 24) that could impact placement.
5. The engineer identifies suitable locations for sensor placement, adds the sensor and coverage area to 2D floor plans and repeats the process until the target areas are sufficiently covered.

Given the complexity of the above process, it is not surprising that very often the sensors are placed incorrectly. There is a clear need in the industry to automate the sensor placement process. Streamlining the process using automated tools can help to reduce the errors, time, efforts and costs [3, 4].

Some vendors provide AutoCAD plug-ins with a built-in library of 2D sensor drawings and coverage area patterns (see Fig. 2(a)). These tools are very primitive and meant only to save time spent on drawing sensors and coverage patterns. The entire process is still manually driven. Since 2D drawings are non-computable, it is not feasible to automate sensor placement using 2D drawings. However, with the advent of Building Information Models (BIM), which is a collection of computable databases of building components, it is feasible to automate sensor placement.

BIM is a semantically rich digital representation of physical and functional characteristics of a facility. Due to proven benefits of the BIM methodology, many countries have mandated the use of BIM for governmental projects (e.g., UK, Denmark, Netherlands and Singapore) [5]. In the US there exists a national BIM standard and large institutions such as DoD and GSA have adopted BIM methodology. Inspired by this growing adoption of the BIM paradigm and its benefits to all stakeholders, we developed a software tool that automates the selection and placement of sensors (Fig. 2(b)) and overcomes the aforementioned issues.

Sensor Selection and Placement Tool

The building information model contains a detailed geometry of building elements. The spatial element (typically, spatial element represents a room in a building model) is the unit in which the sensor placement algorithm runs. A building model can be divided into a number of spatial elements (e.g., rooms). The tool loads the BIM model of a building developed by the architects (See Figure 2(b) for the workflow). The user of the tool can specify criteria for sensor placement such as 1) alignment with workstations and furniture layout; 2) compliance to a code or standard; 3) objectives for optimization (e.g., minimize cost, maximize coverage, etc.); 4) Luminaire grouping method (e.g., how many luminaires are controlled by a sensor); and 5) areas to be covered.

In step 1, the geometry of spaces such as windows, doors, space boundaries and ceiling height are retrieved from the building model. Then, the electrical, mechanical structures, and physical objects that impact sensing performance e.g. luminaires, HVAC vents and windows are identified in building models.

In step 2, the function of the space guides sensor model selection. The function of a space is identified such as a conference room, a restroom, a corridor, etc.

Figure 2: Current and new workflows for sensor placement
In step 3, the tool retrieves models of sensors of interest from a central repository (e.g., Autodesk’s SEEK database or manufacturer’s website). These models are made available by sensor manufacturers and have in-built placement rules and sensor geometry information such as sensor type, suitable space (e.g., conference room, private office, restrooms etc.), coverage area (as a function of ceiling height), and mounting location (ceiling or wall mounted). Table 1 shows an example of rules for sensors.

Based on the space geometry and its function, suitable sensors are identified from a list of available sensor models and subsequently their properties are listed in the parameter definition file. For example, assume all the sensor parameters are stored in a database. In this case an SQL query is issued to select combined photo and motion sensors for private office with a coverage area larger than 100 square feet.

Table 1. Example of sensor parameter definition file

<table>
<thead>
<tr>
<th>Group</th>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor manufacture</td>
<td>Manufacturer name</td>
<td>Philips</td>
</tr>
<tr>
<td></td>
<td>Sensor model</td>
<td>LRM1763</td>
</tr>
<tr>
<td>Sensor cost</td>
<td>Cost</td>
<td>$xx</td>
</tr>
<tr>
<td>Sensor model geometry</td>
<td>Image</td>
<td>.jpg file</td>
</tr>
<tr>
<td></td>
<td>Dimensions</td>
<td>Diameter = 88 mm</td>
</tr>
<tr>
<td>Sensor location</td>
<td>Room type</td>
<td>Open office/conference</td>
</tr>
<tr>
<td></td>
<td>Mounting</td>
<td>Ceiling</td>
</tr>
<tr>
<td></td>
<td>Constraint - Height</td>
<td>&lt; 4m</td>
</tr>
<tr>
<td></td>
<td>Constraint - Window</td>
<td>Facing window</td>
</tr>
<tr>
<td></td>
<td>Constraint – Door</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Constraint – Air terminal</td>
<td>&gt; 4”</td>
</tr>
<tr>
<td>Motion-sensor</td>
<td>Coverage area</td>
<td>Rectangle, 2.5h (width) x 3.75h (length)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>h = ceiling height</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Max 5.4 m x 3.6 m (2.4 m ceiling height)</td>
</tr>
<tr>
<td>Photo-sensor</td>
<td>Coverage area</td>
<td>Square, 1.5h (width) x 2.0h (length)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>h = ceiling height</td>
</tr>
</tbody>
</table>

In step 4, the rules governing the placement of sensors are read from the sensor model file (e.g., avoid windows and vents). User inputs such as applicable building codes and standards are also considered. In Revit, this information can be retrieved through an API. The coverage area for each sensor type is calculated based on mounting location (e.g., ceiling height or distance from wall).

In step 5, optimal locations for sensor placement are identified by solving an optimization problem subject to many constraints such as 1) sensor functions (e.g., motion detection or photometry), 2) shape of sensor coverage area (square, circle, rectangle, or ellipse), 3) sensor mounting (e.g., wall/ceiling-mounted), 4) minimum and maximum distance from window/door/vent/ceiling, 5) room geometry (e.g., interior partitions) 6) luminaire grouping (e.g. upper limit on luminaries controlled by one sensor), 7) coverage area (e.g. union of coverage area of individual sensors sufficiently covers the target area), 8) user specified constraints and 9) alignment of ceiling grids. The sensor placement optimization algorithm has the ability of automatically deploying sensors based on user-defined objectives (minimizing the number of sensors, costs, maximizing system performance and/or no more than 10% of area is left uncovered, etc.).

In step 6, the performance of the derived solution is simulated. In the next step, compliance with code and performance requirements are checked. If the solutions is found non-compliant then the process moves back to step 3 to evaluate alternative solutions.
In step 7, the most suitable sensor placement solution is selected. Sensors are inserted in BIM. The location and true coverage area of each sensor is shown on the floor plan wherein the coverage area is bounded by walls and other physical structures.

Validation of the Sensor Placement Tool

The method is implemented as a Revit plugin and applied to a building model with 11 rooms (Fig. 3). The runtime is less than two seconds for all the rooms. Figure 4 shows the results of automatic placement of two varieties of sensors using the plug-in: Motion sensor coverage areas are shown in Fig. 4 (a), and photo-sensor coverage areas are shown in Fig. 4(b). In Fig. 4 (a), some areas are uncovered because target coverage area is set to at least 80% of total area. This parameter is adjustable. Higher target leads to more sensors being deployed.

Impact of the Tool Relative to State of the Art

Workflow optimization

- The automatic placement does not require engineers to manually reference datasheets and follow through placement guidelines. Instead the guidelines are built-into the software tool.
- This method can automatically address code compliance issues.
- The automatic placement algorithm can be optimized for various objectives. It is very difficult to optimize objectives in manual placement scenario.
- If the building design or layout of the furniture is changed then the new positions of sensors can be quickly determined.

Energy savings

- Optimal placement of occupancy sensors will mitigate the false positives caused by HVAC vents and line of sight continuing beyond doorways. It will also avoid false negative occupancy detections caused by line of sight being blocked by partitions.
Optimal placement of photo-sensors will address over-dimming and stability in light output issues which are the main causes of occupant complaints. By addressing these issues we believe that the acceptance of photo-controlled lighting system will be increased.

Cost savings
- Automatic placement avoids installation errors and costly onsite rework.
- One click solution alleviates the need for training and domain knowledge. Architects, designers, consultants, sales persons, quotation engineers, and non-experts can use the tool.
- In current practice, sensor deployment planning can take days to weeks depending on the size of the building. The tool can cut down this time to minutes saving enormous labor.
- The tool enables comparison of multiple options for sensor selection and placement. Optimized solution reduces bill of materials.

Comparison with Other Tools
- We use Autodesk Revit to automatically place sensors where existing tools use Autodesk AutoCAD. The AutoCAD drawings are not computable whereas Revit models are computable database of structures. Revit allows us to automatically identify the size of the room, center of the room, locations of doors and windows, etc. Our tool exploits this information to comply with placement guidelines (e.g., do not place photo-sensors near windows) and show true sensor coverage patterns.
- Since the Revit files may contain the room type and size information, our tool can automatically select the best suited sensor model based on the size and function of the room.
- Our tool can compute the true coverage areas based on ceiling height, walls and partitions. The existing tools do not consider the geometry constraints of the space.
- Our tool automatically places sensors in the building models while complying with guidelines laid out by the manufacturer. On the other hand existing tools do not offer any kind of automation.

Summary
We developed methods for automatically deploying sensors in BIM models. The method optimized the sensor placement workflow and has energy and cost saving potentials. A plug-in was developed in Autodesk Revit to illustrate and validate the method. Two sensor family files were created in Revit to embody manufacturer specified placement rules. The plug-in automatically optimizes sensor location using optimization methods, and provides true coverage information and bill of materials information. The results show that the method can greatly improve the efficiency of the sensor placement and by this also reduce the cost. A limitation is that more criteria (e.g., shading and orientation) besides sensor coverage and quantity may be considered when daylight sensors are placed.

References