# Improving Building Energy Efficiency by Kinect-based Occupancy Tracking and Mobility Detection System

some authors

## ABSTRACT

In an average open office building, air conditioning, ventilation and lighting account for 30 to 40 percent of energy consumption. Nowadays, most modern conditioning systems in buildings still operate based on occupancy rather than actual usage. Such operation mode creates needless conditioning and energy waste. Therefore, in order to achieve an optimal conditioning state based on traffic in zones of interest, we need to know the rate and time of occupancy and intelligently tune the system according to the number of actual occupants. In our study, we use a people counting software based on a network of Microsoft Kinect for Windows sensors in order to acquire temporal occupancy information. The occupancy counter software provides real-time occupancy data through detection and tracking of people in the building. An HVAC management and control system needs to adjust this data in real-time and measure the local level of comfort. In this research, we propose an approach for energy saving which integrates a real-time occupancy data into building management systems. This approach leads us to the creation of an occupancy monitoring and control system which takes into account three elements: subject mobility, room status (e.g. empty, occupied, crowded) and actual number of people. In addition, in order to model the occupancy data collected, we use the Markov chain principle where a state is a combination of the statuses of existing zones in the building. Such state represents the level of energy consumption in real time and a useful input data for the HVAC system controller. Here, we demonstrate that our model, based on data collected by an ensemble of Kinect sensors, can be integrated with an HVAC control strategy to achieve substantial energy savings. Through the prediction of future occupancy level of particular zones of a building, our intelligent system is able to adjust conditioning parameters gradually to reflect the predicted changes in time.

**Categories and Subjects:** [Computer systems organization]: *Embedded and cyber-physical systems*: *Sensors and actuators*

**General Terms:** Algorithms, Design, Management

**Keywords:** Wireless Sensor Networks,

## 1. INTRODUCTION

A 2009 report by the United Nations Environment Program (UNEP SBCI) [**?**] has clearly identified construction buildings as responsible of a significant amount of global energy use and greenhouse gas emissions in both developed and developing countries. Although most local governments have taken steps through regulations and policies to reduce energy use and gas emissions, their efforts have had little impact in the past. In addition, these measures are likely to meet some resistance in the future because they may not serve the economic interests of the many stakeholders involved in the building sector. Therefore, there is a need for an innovative system that implements energy efficiency measures. Such system would provide locally small energy-reduction opportunities for each of the millions of buildings across the globe.

At the core of energy consumption in buildings, are Heat Ventilation And Cooling systems (HVAC) which are mostly designed to operate at full capacity under the assumption of normal occupancy of rooms at all time. Although current HVAC systems are equipped with sensors, their management and control systems ignore the dynamic nature of daily occupancy of buildings. In addition, they are unable to proactive adjust to occupants' comfort levels. Understanding human mobility and occupancy patterns are key factors in successfully managing energy in buildings. Building occupancy has been the subject of intensive studies in the past years. Several approaches using building occupancy data to improve prediction and simulation of HVAC control have been proposed. In the same perspective, the main objective of our paper is to propose an energy-saving model based on occupancy patterns of human mobility in buildings. This model offers a solution for the management and control of HVAC systems in smart buildings. The most important features of the system that implements this model are the following:

1. The *detection and tracking of people in real time* in the building provides accurate occupancy data of an entire building divided into several related zones.

2. A *Occupancy Counter Software* carries out the detection, tracking and monitoring process based on multiple Microsoft Kinect for Windows (K4W) sensors distributed in strategic locations in the building.

3. A *prediction of future occupancy* of the building is introduced through the use of a Markov chain (MC) which models the collected occupancy data. MC is a suitable because it captures the temporal nature of occupancy variation along with inter-room correlations and occupant usage. Unlike most building occupancy techniques described in the Related works Section **??**, our approach implements an occupancy counting technique that is based on the Microsoft Kinect for Windows (K4W) device.

**Organization:**This paper is organized as follows: In Section 2, we present relevant background information about human detection and tracking techniques and tools as well as the most popular occupancy counting and sensing devices. In particular, we mention the Microsoft Kinect for Windows that is central to our experimentation. Next, in Section **??**, we discuss about the design and implementation of our solution to energy-saving problem in smart buildings. Here, we give a detailed account of the setup of our human mobility tracking and detection system based on a occupancy counter software using the Kincet for windows sensor. In Section **??**, we expose several approaches using building occupancy data to improve prediction and simulation of HVAC control. These approaches use models or techniques that are related to our study. Then, in Section **??**, we displays the results and evaluations of our real world test-bed conducted in an open office laboratory. In Section **??**, we conclude our paper and propose some perspectives.

# 2. BACKGROUND

This section presents background information on human detection and tracking approaches and related techniques as well as the most popular sensing devices. In particular, it gives a brief description of the Microsoft Kinect for Windows (K4W) sensor. In addition, we give an overall picture of the methods and counting logic useful to our occupancy counter software.

## 2.1 Human Detection and Tracking

Human detection and tracking (HDT) is an active research subfield of object recognition. Detecting the presence of humans in a particular environment and planing resources accordingly are at the core of many problem-solving strategies in construction management. Human motion tracking includes capturing body displacements and limb movements such as postures and gestures of human targets. These strategies should be able to predict through a learning mechanism, an acceptable number of occupants of a room [**?**]. Such prediction is important in overcoming the necessary time delay between signal detection and appropriate temperature.

### *2.1.1 Approaches in HDT*

HDT is by nature a complex process that includes issues as simple as adequate sensing to the delicate data-mining techniques. It is a challenging task for a number of reasons. The common obstacles to quality detection and tracking are ambient noise, device imperfection, environmental factors variation, fluctuation of data collected, background signal similarity and sometimes, intentional deception (adversarial scenario). Our interest in this study is limited to the well known spatio-temporal properties related to the position and history (tracks) of human present in a given environment. These properties are presence, count, location, track and identity.

### *2.1.2 Sensor Technologies for HDT*

Several kinds of counters that require contact with people, such as turnstiles, are used because contact type counters count very accurately. These counters, however, cannot be applied to spaces within commercial buildings because, except at a few critical places (e. g. , entrances), they obstruct the normal flow of people in work spaces and would require installation in each room [**?**]. Several kinds of sensors currently can provide information on occupancy, such as video cameras equipped with occupancy counting software, optical tripwires and pyroelectric infrared (PIR) motion sensors that count the number of people crossing a particular area. Wireless sensor networks have been widely used as supported technologies for monitoring, tracking and controlling Human Mobility. Most of studies designed a WSN for occupancy detection and result data analysis to send a final control function to the thermostat for HVAC monitoring. The authors of [**?**] highlighted another approach in occupancy detection by using sensors called Tiny Agents (TA) to control power consumption in a building. The tiny agents are distributed throughout the building and deployed in air-conditioning system to capture and send room temperatures and interact with the AC or other agents.

### *2.1.3 Occupancy Counters*

An Occupancy Counter is a system that counts the number of persons entering and exiting a room. Many devices based on several technologies (ex. Cameras, infrared beams, vision) have been used with various level of success in commercial systems to count people indoor and outdoor.Remarkable research using 1) neural networks to count subjects in video images and 2) algorithms that use single or multiple lines as counting zones have also been proposed.

## 2.2 The Microsoft Kinect Sensor

The Kinect sensor is a motion sensing device with an infrared depth sensor , an emitter and a microphone sound system built around an maleable RGB camera as shown in Figure 1. Kinect array specification include a 43 degrees vertical angle viewing and 57 horizontal degrees of field of view. This is a motion sensing input that enables a user to remote control a host system via gesture and sound commands. Optical and acoustical detections are the motion sensing that can be electronically identified. Infrared light or laser technology may be used for optical detection because Kinect is an electronic sensor. The Kinect sensor also performs functions such as voice recognition, facial recognition, and skeletal tracking along with motion detection [**?**]. The depth camera, a virtual camera, is the result of displacement matching on the IR projector and real IR camera, each equipped with its own lens distortion. The depth data from Kinect sensor is the distance, in millimeters, to the nearest object at that particular (x, y) coordinate in the depth sensors field of view.

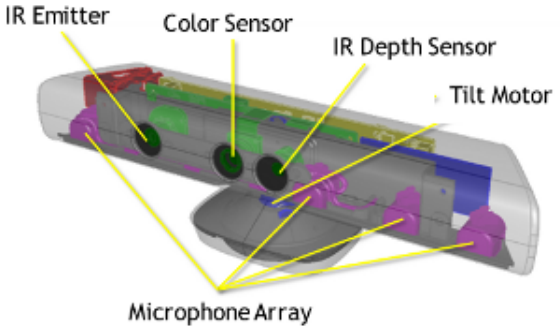


**Figure 1: Kinect component**

There are a variety of open source libraries for Kinect programming using PC's like libfreenect, openni and SDK. Open Kinect [**?**] is community of people who use libfreenect, a free and open source library for enabling Kinect programming in PCs run by Windows, Linux, and Mac. OpenKinect support many wrappers like python, c++, c]. The official library from Microsoft Kinect SDK provides features like color images, depth images, audio input, and skeletal data. The tracking mechanism in software technology used in Kinect enables advanced gesture, facial and voice recognitions.

# 3. REFERENCES