II. REAL-TIME DOCK DOOR MONITORING SYSTEM USING A KINECT SENSOR

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Abstract

This study presents a proof of concept where a single Microsoft Kinect sensor is used for automated monitoring of a dock door in real-time. The proposed system will automatically and in real-time: (1) detect when an object breaches the dock door perimeter, and its corresponding speed and direction, (2) count the number of pallets loaded/unloaded to/from a trailer, (3) record the loading/unloading time of each load, and (4) reconstruct an image of every loading/unloading trip at a dock door, irrespectively of the material handling travel speed and direction. Particular emphasis is given to discussing how to extend the proposed concept by using multiple Kinect sensors, the technological challenges for implementation, and the expected benefits of a real-time dock door monitoring system

1. Introduction

Dock doors are the entry/exit point for inbound/outbound loads in most manufacturing, storage, and distribution buildings. Dock doors that are used to receive loads are called inbound, strip, or receiving doors; whereas dock doors used for shipping loads are called outbound, stack, or shipping doors. Although, dock doors could serve as both inbound and outbound on a given day, in practice, they tend to be dedicated to one of these operations. In most warehouses and distribution centers, inbound and outbound doors are located in different areas known as the receiving and shipping docks, respectively. Receiving (and shipping) docks usually have numerous dock doors to unload (load) multiple trailers simultaneously.

Receiving dock operations typically include unloading from trucks or trailers, inspection and quality control, labeling, and transporting the loads to their storage locations. On the other hand, shipping dock operations may include picking, order consolidation, palletizing, wrapping, labeling, and loading onto empty trailers or trucks.

An automated dock door monitoring system could provide valuable real-time data on receiving and shipping dock operations. The data collected may be used to help dock managers to: remotely visualize the docks' status, monitor current and projected productivity standards and performance metrics, and manage dock operations (including supervising employees, job prioritization, trailer/truck security, and traffic safety enforcement).

This work presents a *proof of concept* for a dock door monitoring system using a single Kinect sensor. The proposed system will automatically and in real-time: detect when the dock door perimeter has been breached and at what speed and direction, count the number of pallets loaded/unloaded to/from a trailer, record the loading/unloading time of each load, and reconstruct an image of every loading/unloading trip at a dock door, irrespectively of the material handling travel speed and direction.

The remainder of this work is organized as follows. Section 2 presents an overview of the most common sensor technologies in warehouses. Section 3 describes the proof of concept for a single dock door real-time monitoring system using a Kinect sensor. Section 4 describes how the proposed concept may be extended by using multiple Kinect sensors. Section 5 discusses the technological challenges and expected benefits of the proposed dock door monitoring system. Lastly, Section 6 presents our conclusions and future work.

2. Overview of Sensor Technologies in Warehouses

This section briefly describes and evaluates the most common sensor technologies used in warehouses in terms of their potential to be used as a dock door monitoring system. The following technologies are considered: photoelectric sensors, radio frequency identification technology, high definition cameras, and 3-D range sensors.

Photoelectric sensors send a beam of light from an emitter to a receiver. Objects are detected when the (light) communication between the emitter and receiver is interrupted. These sensors are commonly used to activate automated equipment such as pallet wrapping machines and AS/RSs, and to activate automated lighting and doors. Unfortunately, although photoelectric sensors may detect objects, they cannot recognize them. Hence, this sensor would have to be combined with other sensors if used as part of a dock door monitoring system.

Radio frequency identification (RFID) technology uses radio-frequency electromagnetic fields to transfer data. RFID technology includes an RFID tag and a RFID reader [1]. In 2004, the Gillette Company filed a patent [2] that presented the framework for an RFID system with capability of tracking products at different points in a distribution chain. The main challenge with using RFID technology as part of a dock door monitoring system is that RFID tags need to be placed on the loads in order to be recognized. Hence, the technology is not feasible for unloading operations (as loads are identified after being unloaded) and the system can be easily manipulated by removing the RFID tags.

High definition cameras are capable of taking high precision red-green-blue (RGB) images commonly used for processes that require fast color imaging tasks such as packaging and color printing. This technology can be used to obtain and manipulate RGB data for applications such as object tracking [3][4], but it does not provide the required data to reconstruct the surface of an object, obtain time samples, and measure speed.

Range imaging technology has been around since 1970s [5]. This technology, also known as *range* or *depth sensor technology*, include single point and laser scanners, slit scanner, patter projection, and time-of-flight systems. Since then, low cost commercial systems have been developed with the capability of providing full 3-D images that can be used to reconstruct the surface object based on depth data. The main limitation of these sensors includes poor readings due to background light, shadows and reflections, and reading interference.

Ideally, a real-time dock door monitoring system would include multiple sensor technologies. The next sub-section describes the Microsoft Kinect sensor, which incorporates a depth sensor, RGB camera, and microphone.

1.1 Microsoft Kinect Sensor

The Kinect sensor is a low-cost depth sensor that was designed as an add-on peripheral for the Xbox in 2010. Microsoft introduced a second generation Kinect exclusively for developers in 2012, named Kinect for Windows. The Kinect sensor has the capability of providing depth and color data for each pixel of an image.

The Kinect for Windows sensor, shown on Figure 1, consists of an infrared (IR) emitter, which projects an infrared pattern onto objects in the sensors field of view, and an infrared camera that detects the changes in the IR pattern. It also contains a RGB camera, a 4-microphone array, and a tilt motor to adjust viewing angle. The sensor has an angular field of view of 57° horizontally / 43° vertically, with the capability of tilting up to 27° up and down. This sensor is capable of providing depth and color images at a maximum of 30 frames per second, at its default resolution is 640×480 pixels.

The range for the depth sensor is 0.4–4.0 m (1.3–13.1 ft.). The microphone array features four microphone capsules, with each channel processing 16-bit audio at a sampling rate of 16 kHz. In summary, the Kinect is capable of capturing 3D motion, facial recognition, voice recognition, and acoustic source location, while suppressing ambient light and noise. For further information, operating capabilities and comparisons of the Kinect sensor the reader is referred to [6] [7] [8] [9] [10].

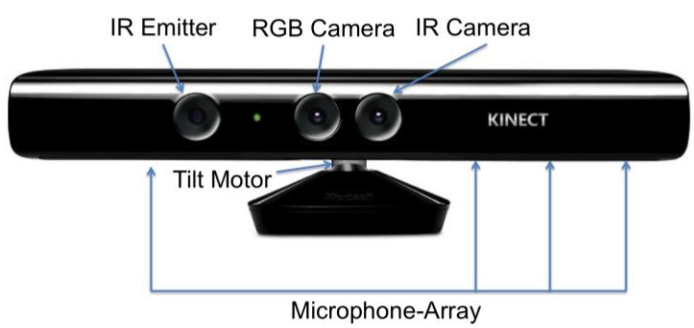


Figure 1: Kinect for Windows

The Kinect sensor has been successfully used to develop a real-time ergonomic monitoring system using the skeletal tracking capabilities of the sensor [11]. It has also been used in studies for facial recognition [12] [13] and real-time object tracking [14]. The Kinect was also used for a warehouse related study focused on order picking [15], where the authors introduced a monitoring approach based on RGB and depth data to recognize and monitor different box-shaped picked items.

We believe the Kinect for Windows is an appropriate technology for real-time dock door monitoring. In the following section, we present a proof of concept of how the Kinect sensor may be used as part of a real-time dock door monitoring system.

3. Proof of Concept of Dock Door Monitoring System

A small-scale controlled-setting environment was designed as a proof of concept for the real-time dock door monitoring system. The setting, depicted in Figure 2, includes a Kinect sensor mounted on a wall overlooking a tabletop, which represents a dock door. Over the tabletop in Figure 2 one can also note that the Kinect sensor is connected to a laptop computer that controls the sensor. Figure 3 shows a top view of a region on the tabletop that represents the inside of the dock.

Figure 2: Camera Setup

Our objective is to demonstrate that the Kinect sensor may be used as a low-cost real-time dock door monitoring system. The proposed dock door monitoring system will use the Kinect depth sensor to monitor changes in depth while objects pass below the sensor, just as if it was placed over a dock door for monitoring. This section will discuss the setup and workspace used, followed by an overview of the application developed to measure speed, time, and occurrences of objects passing below the sensor.

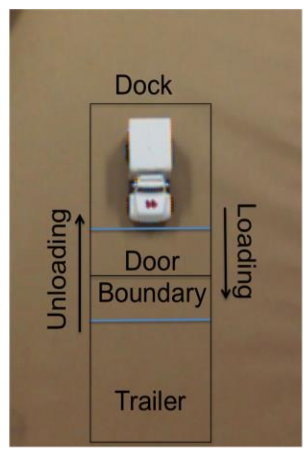


Figure 3: Dock Door Setup

The sensor was placed vertically on a wall, facing down approximately 1.0 meter above a worktable, as seen on Figure 2. A portion of the table was covered in brown paper to avoid the reflection of light on a glossy surface as it may cause invalid depth readings. (In our prototype, the close proximity of the sensor, combined with a shiny surface of the table, and strong indoor illumination created reflectance problems. However, we understand that refelctance should not be a major issue in real-life docks.)

An application to control the Kinect sensor was written in Visual Studio using the *C#*. Figure 3, shows an example where a toy ambulance is used to represent a material handling equipment about to enter a trailer. We will observe depth changes in three over-imposed lines in order to detect breaches (*i.e.*, an object approaching the dock door). *Line 1* (blue), located just below the truck in Figure 3, is used to recognize that a load is approaching toward the trailer. *Line 2* (black), labeled "door boundary", marks the division between the dock and trailer. Although *Line 2* is located inside the dock, any load that crosses this line is considered to have left the dock. *Line 3* (blue) is located just below *Line 2* and is the inbound counterpart of *Line 1*. The approaching speed of an object is computed based on the time and distance between *Lines 1* or *3*, and *Line 2*.

In a loading scenario, a breach in *Line 1* marks the beginning of a loading movement (*i.e.*, an object is being loaded to the trailer). The object moves toward the trailer until *Line 2* is breached; here, the time difference between both breaches is used to calculate entry speed, and a truck-entry counter is increased. The same concept applies for an unloading scenario; the only difference is that we evaluate an object exiting the trailer. In unloading trips *Line 3* will detect a breach instead of *Line 1* and the breaches will be added to a second counter used to log exit occurrences.

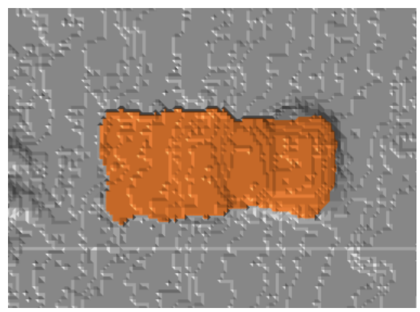
The application developed also records the total time a material handler spends inside the trailer (i.e., the time it takes to either to unload or load a single pallet) and the total time incurred to load or unload a trailer.

Besides recording travel speeds and entry/exit count and timestamps, the application also records two additional sets of information for every breach: a color image screenshot and a depth data surface plot reconstruction. Figure 4a, shows a toy ambulance used to test the programs' ability to export depth data in real-time for a moving object. As soon as the toy ambulance breached *Line 2* (*i.e.*, there was a depth change in the line) the depth data from the sensor was used to automatically create the surface plot in Figure 4b. Note that Figures 4a and 4b are both taken for a moving object and generated automatically.

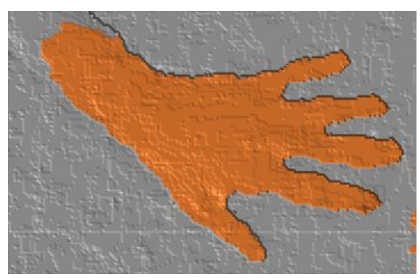
In a real life scenario a color screenshot with date and time could be used for accountability of excess speed events, it could also be used to find confirm pallets have been received, and to aid in tracking of missing or unlabeled pallets. Furthermore, it could be used to document who had access to a particular trailer, which is vital for security sensitive trailers.

A depth data-based surface plot would be used to recognize, document, and differentiate objects that interact with the trailer: either a person or a material handling equipment (with and without a load). The object identification will depend on the dimensions of the object, which may be obtained by analyzing the depth data.

(a) – Color image



(b) – Depth surface plot



(c) – Hand depth surface plot

Figure 4: Depth Plots Using Kinect Sensor

During this exercise, while plotting multiple objects passing below the sensor, we noticed that the borders of the objects are not as accurate or smooth as a color image. Figure 4c, presents a surface plot of a hand, which has a different geometry than the previously tested. It is observed that the separation and width of some fingers appears to be distortional. Although in this experiment we are evaluating smaller objects (with smaller details), than required for real-life docks, we must consider improving the accuracy of the reconstructed image from the depth sensor by using methods such as the ones described in [16].

Figure 5 presents a screenshot of the graphic user interface (GUI) developed as part of the *C#* application to control the Kinect sensor. The two images on the top of Figure 5 are real-time depth (left) and color (right) frames from the Kinect sensor. The numbers of the lower-left portion of Figure 5 provide counters, time and speed data from the last breach, as well as well as depth measurements for the three (over-imposed) lines. On the middle-bottom of Figure 5 there are controls for the sensor tilt and to manually capture and record images such as the one presented on the lower-right of the figure. In the developed application the images are taken automatically when a breach occurs. These images are stored in the computer.

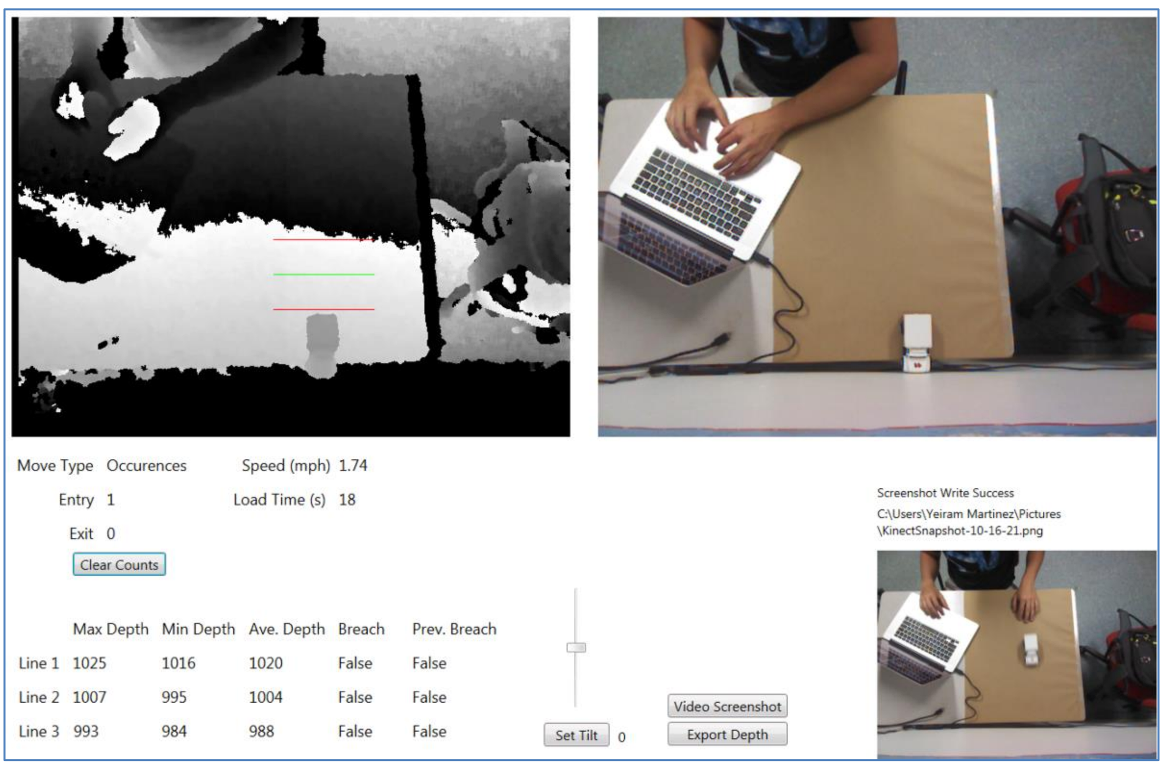


Figure 5: Screenshot of GUI

The small-scale concept shows that the Kinect sensor may be used as part of a real-time dock door monitoring system that automatically identifies perimeter breaches, logs timestamps, monitors entry and exit speed, and exports a color image screenshot together with a depth data based surface plot. Since the Kinect sensor is controlled by a computer, the obtained data may be stored and analyzed in the computer or sent to a database so the information is shared.

4. Multi-Kinect Dock Door Monitoring System

In Section 3 we presented a concept for a single dock door monitoring system. In this section we discuss the challenges involved in extending the single-Kinect concept to a multi-Kinect environment.

Given the sensor range of the Kinect sensor, we envision using one Kinect sensor per dock door. These sensors could either be connected to individual computers or connected in parallel to the same computer. If Kinects are connected individually, then it would be equivalent to having multiple single-door monitoring systems. Clearly, this option would require a larger investment (in computers) and would slightly increase electricity cost and resources required to store data from multiple sources. On the other hand, if multiple Kinects are to be connected to the same computer, then USB bandwidth and power requirements may become an issue. Irrespectively of how the sensors are connected to the computers, a central computer or database would be required to unify the information from all the sensors in order to conveniently present the information to management.

Another aspect to consider when using multiple sensors is the interference problem caused by the overlapping of the Kinect field of view. This occurs when a second sensor confuses the IR pattern projected by a first sensor with its own. Several academic studies have developed methods to reduce overlap interference of multiple sensors operating simultaneously [17] or the use of multiple sensors for indoor human tracking [18]. A sensor-scheduling algorithm for object tracking using four Kinect sensors operating simultaneously was proposed in [19].

Developing such system would be a great advantage because we would be able to monitor, measure, and document all incoming and outgoing material in real-time.

5. Discussion of Concept Implementation

A real-time dock door monitoring system would facilitate and improve dock supervision in manufacturing, storage, and distribution buildings. It would aid managers to remotely monitor a live video feed video of unloading/loading operations and verify historical data of entry/exit instances on a given dock door. It would also increase safety as approaching speeds would be constantly monitored and speed-safety violations would be documented with a picture and time of the occurrence for accountability purposes. Furthermore, the ability of this system to automatically log timestamps allows daily dock door metrics to be monitored in real-time; allowing management to predict performance and prioritize jobs or dock doors. Also, personnel performance could be compared in order to determine who performs better under certain conditions, *e.g.*, loading/unloading heavy or tall pallets difficult to handle. This information is key for assigning jobs or balancing workloads in order to reduce unloading/loading times. The proposed real-time dock door monitoring system could also be used to monitor dock operations trainees to understand when they are far enough into the learning curve as to be able to perform well in a real dock environment.

The cost per door of implementing the Kinect sensor-based real-time dock door monitoring system is relatively low. The current generation of the Kinect for Windows costs approximately $250, whereas each desktop computer costs a few hundred dollars. Alternatively, any Window-based computer could be used to connect to a virtual computer. The assembly of the system would require a sensor to be strategically placed above each door. It might also require extended USB and power cables, and internet access, depending on the location of the computer and connection requirements.

6. Conclusions and Future Work

This study presents a proof of concept for of a Kinect-based automated real-time dock door monitoring system. An automated dock door monitoring system could provide valuable real-time data on receiving and shipping dock operations. The data collected may be used to help dock managers to: remotely visualize the docks' status, monitor current and projected productivity standards and performance metrics, and manage dock operations (including supervising employees, job prioritization, trailer/truck security, and traffic safety enforcement).

The proposed system has the capability to automatically identify when objects approach a dock door, records timestamps that can be used for time studies and performance monitoring, measure the time incurred in loading/unloading individual loads and trailers. The system can also monitor approaching speeds, which may be used to monitor safety compliance. Time and speed data could be used to compare the difficulty in handling tall and heavy pallets with short and light pallets to assign the corresponding time allowances while developing work standards. The developed prototype of the system also automatically exports a color image screenshot to document all incoming and outgoing material and personnel, and address any accountability issues related to excess speed events or trailer safety. It also exports a depth data frame that can be used to recognize objects that pass below the sensor. The advantage of using the Kinect sensor is its cost, combination and quality of sensors, and the capability to control it with a computer using customized software.

We will continue this work by implementing and validating the system at an actual dock door from an industrial collaborator using the next generation of Kinect for Windows. The second generation of Kinect for Windows is expected to be released in summer 2014. The new generation sensor has a range up to 4.5 m (14.8 ft.), a wider field of view with a sharper depth image and a 1080p color stream resolution, and is capable of facial and expressions recognition. Once the dock door monitoring system is validated we will focus on developing a Kinect-based dock management system, to aid management in the operational level decision-making process.

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