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Interactive Sensor Visualization for Smart Manufacturing System

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This paper presents a case study of augmenting an electronic screen with a projected display to help visualizing sensor data in a smart manufacturing set up. The visualization module displays both spatial and temporal data and by holding a semi-transparent screen in front of an electronic screen, a user can augment spatial information with temporal trend or vice versa. The system also supports interaction through an interactive laser pointer and is integrated to an early warning system to alert any deviation in sensor readings in the contexts of environment and people tracking.

Smart Manufacturing; Augmented Reality; Information Visualization

1. INTRODUCTION

This paper presents an interactive visualization module for people, equipment and environment monitoring for a smart manufacturing process. A smart manufacturing process usually consists of a plethora of sensors and the success of the process often depend on successful utilization of sensor data. An automated decision making process is often not possible due to the different range of requirements for different manufacturing processes, equipment and geographic locations. Our proposed system aims to help a person to take efficient decision by analysing various sensor data. Representing both temporal data and spatial locations of sensors in a single screen is challenging while setting up a 3D visualization system either requires users to wear a 3D headset (like Google cardboard or Oculus Rift) or setting up a special display (like Autostereoscopic display). We propose a new laser pointer based input device and a projected output system that can augment large-sized electronic display with more data than a single display. The rest part of paper presents existing visualization systems for smart manufacturing process followed by a description of our proposed system.

2. BACKGROUND

A smart factory is based on the idea of Smart Manufacturing or Industrie 4.0, which promises to embrace the 4th industrial revolution (DFKI (Deutsches Forschungszentrum für Künstliche Intelligenz). The first industrial revolution (late 18th Century) was fuelled by mechanisation with steam-power, the second (early 20th C) by electrification and mass production, and the third (1970s) by use of electronics and IT for automation. The fourth industrial revolution is characterised by self-awareness and autonomy, where the factory should collect data about its elements (i.e. be self-aware about people, machines, environment etc. of the factory system) and self-assess [Wang et al, 2015], taking its own decisions (autonomy) [Lee et al., 2014]. “Industrie 4.0 describes a production oriented Cyber-Physical Systems (CPS)” approach [Wang et al. 2015] that is driven by real-time data and is fully-integrated and collaborative (NIST) to blend “information, technology and human ingenuity to bring about a rapid revolution in the development and application of manufacturing intelligence to every aspect of business” [Chand & Davis 2010].

Existing visualization techniques for smart manufacturing explored representing relationship among data through establishing ontologies and visualizing network diagram among different items [Vrba 2011; Chakrabarti 2017]. Sackett [2006] presented a review on existing visualization techniques but did not provide detail on visualizing both temporal and spatial information

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simultaneously. Existing smart manufacturing set up at Cranfield and Sheffield universities are exploring using state-of-the-art virtual reality, augmented reality and projected displays (e.g. Microsoft Hololens) mainly for explaining individual components or working principle of complex machines.

3. EXISTING PROBLEM

Existing smart manufacturing processes are investigating large touchscreen (e.g.: Clevertpuch Plus) and different virtual reality systems for visualization although those are not exclusively used to visualize sensor data. Existing augmented reality systems mostly use a tablet computer to zoom in small circuit element or showing descriptions of individual components but not for helping sensor fusion or visualization of sensor data. Our system proposes a cost effective system that can be developed using easily available electronic components to directly manipulate a large screen display and augment it to render more information.

4. PROPOSED SOLUTION

One of the main differences between developed and developing countries in the context of manufacturing is cost and skill of manpower. Any initiative for complete automation in a developing country undermine availability of cheap manpower. Our proposed smart manufacturing system does not only investigate automation but also try to empower existing workforce and will measure the following categories of data

1. **Environment tracking:** There will be a set of sensors set up at different locations of the factory floor to ensure healthy and safe working environment for personnel as well as healthy working condition for equipment. In terms of visualization, we are interested both in spatial and temporal patterns of sensor reading and detecting any dispersion from the designated envelope for safe working of man and machine.
2. **People tracking:** We propose to use non-invasive sensors like visual range and infra-red cameras to detect number of people working at any given time and tracking bad working posture.

Our proposed visualization system (figure 1) will help in making decision by tracking both people and their working environment and consists of the following three parts

1. IoT unit with a single-board computer
2. An interactive visualization module
3. An early warning system

In the following sections we have briefly described each of these modules.

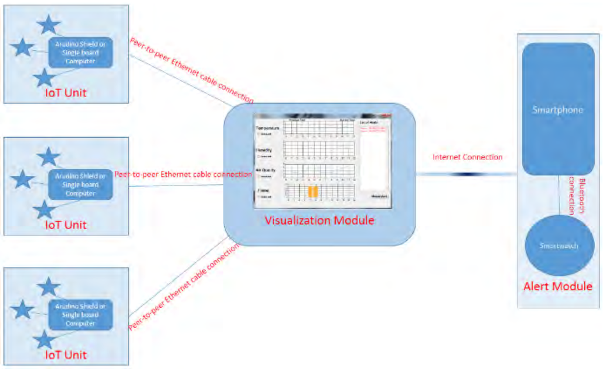


Figure 1. Different Modules of the System

4.1 IoT Node

Each IoT node consist of a single-board computer and a set of sensors. The single board computer records data from different sensors and fuse sensor signals, when required. Presently, we developed the IoT node for environment tracking using MQ-5 Smoke Sensor, HL-83 Flood / Rain Sensor and a DS18B20 Temperature Sensor. In the following sections, we described the interface of different sensors.

Smoke Sensor MQ-2 detects the presence of inflammable gas in air such as LPG, ethanol fumes, propane etc. The sensor has a sensitive filament made of SnO2. In the presence of clean air, this filament tends to have lower electrical conductivity. When a combustible gas such as LPG is introduced, the filament's conductivity rises, and the amount of change in its conductance/resistance can be used to indicate the equivalent gas concentration. While interfacing with Arduino we first calibrate the sensor to get the value of Ro of the surrounding air as used in the datasheet. For that we first run a calibration code with ideal values of Rs/Ro for that particular sensor and based on the Rs_value of the surrounding air we set the value of Ro. While setting up the sensor, we need a 'Burn-in' time or idle time of at least 3 minutes for the sensor to give stable readings. The sensor gives an analog value from 1 - 1023. We scale this value to 0 - 5 V. Rs of the surrounding air is calculated as: RS_gas = (5.0-sensor_volt) / sensor_volt. The value of Ro is taken from the calibration code. The new ratio of Rs/Ro is calculated. Lower is the ratio, higher is the chance of presence of inflammable gas in air. This is because as the concentration of inflammable gas in air increases, the conductivity of the sensitive filament inside the smoke sensor module increases, thereby reducing the resistance Rs.

Rain Sensor HL-83 measures the relative resistance of the collector board, which varies according to the amount of water on its surface. The lower the resistance (or the more water), the lower the voltage output and vice versa. A completely dry board for example will cause the module to output five volts. This sensor also gives analog values in the range 0 - 1023. Lower the value, higher is the chance of getting water detected. We scale that reading down to 3 different scales. If the output is in the range 2-3, then no water detected. If the range is in between 1-2, then slight shower detected and if the range is in between 0-1, then flood is detected.

The **DS18B20 is a 1-Wire digital temperature sensor** provides 9-bit or 12-bit temperature readings using the 1-Wire communication protocol. There are various models (as well as waterproof ones) with different temperature ranges, which supports alarm function using its own on-board non-volatile RAM. For the 1-Wire protocol to work, a 4k7 resistor is connected between the bus wire and power (VCC). The 1-Wire bus is hooked to the GPIO3 pin of pcDuino3. The sensor's VCC is connected to 3.3V of PCDuino. Using the OneWire Library, the temperature sensor is communicated with the PCDuino for the temperature data at a frequency of 1Hz. After establishing a peer-to-peer connection between PCDuino and a PC running Windows using a Null-Modem ethernet cable, the temperature data is streamed to the PC using TCP/IP socket.

Figure 2 below describes the connection of the sensors to a pcDuino single board computer. The black line in the figure shows the connection of the sensors to the in-built Arudino shield of the pcDuino computer while the red line depicts external power supply to the sensors. The pcDuino is connected to a desktop computer running the visualization module over a peer-to-peer connection.

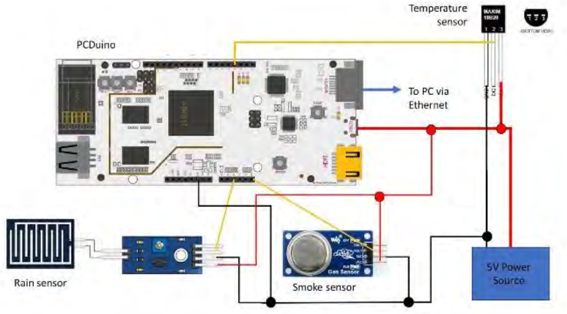


Figure 2. Interfacing sensors to single board computer

Posture Tracking: We also developed an IoT node for posture tracking. We have developed a prototype system using a Kinect that can detect bad leaning posture by measuring the difference between the neck-spine and hip-spine joints in the skeleton figure of Kinect. Following RULA guidelines, it raises an alert when the neck or torso is inclined more than 60º (figure 3). However, unlike other IoT nodes, this node requires a Windows computer to interface with the Kinect sensor.

a. Torso turned less than 60º, indicated by the blue dots in the Kinect Skeleton Model

b. Torso turned more than 60º, indicated by the red dots in the Kinect Skeleton Model

Figure 3. Posture Tracking using Kinect skeleton model

4.2 Visualization Module

This module runs on a standard desktop or laptop computer attached to a screen and a projector. The screen and projector will render the display in extended mode. We have developed a software that renders webcam or CCTV display or just a picture of the floor layout of the factory on one display and sensor reading on the other display. The main electronic display is designed to display spatial information and it is overlaid with information about spatial location of sensors (figure 4). We represented sensor readings by colour code so that a glance at the main display can detect any anomaly in sensor reading and its relative position in the factory floor. The yellow dots in figure 4 changes colour to amber and red based on severity in the reading of sensors.

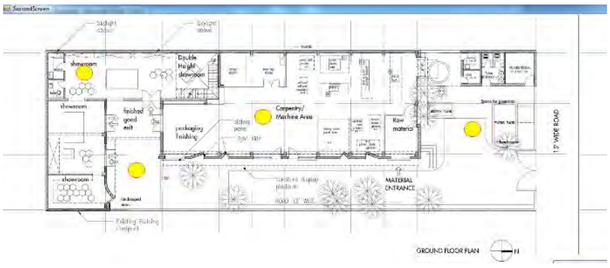
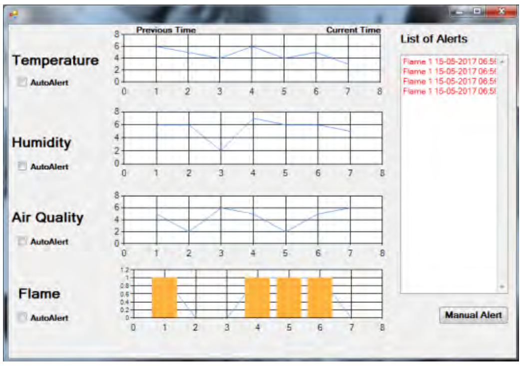


Figure 4. Spatial information of sensors on main display

The projected display is used to render temporal data and shows sensor reading over time as a line graph (figure 5) and out of trend readings are indicated by bar graph. A single button press can switch displays. Both displays can show additional information on sensor reading and surroundings on mouse click events.



Flame 1 15-05-2017 06:5
Flame 1 15-05-2017 06:5
Flame 1 15-05-2017 06:5
Flame 1 15-05-2017 06:5

Figure 5. Temporal information of sensor readings on projected display

A pico-projector renders the display on the electronic screen itself but at a lower brightness level than the screen itself (figure 6). If a semi-transparent sheet (figure 7) is held in front of the screen, then only the projected display turns visible. For example, if a user wants to take sensor readings of a particular part of the assembly line, he holds a semi-transparent screen in front of the main electronic display of the floor and can observe temporal trend of sensor readings (figure 6). The projected screen consists of layered translucent sheet, held together by a frame. The frame also has a handle to hold the device in hand (figure 7).

Considering the widespread use of laser pointer for pointing to specific screen elements is a large display, we developed a special type of laser pointer that can be used to make a left, right or double click at the same location where the laser dot is pointed. We have developed an image processing program to accurately detect the location of the laser dot in a screen from a webcam mage and a calibration routine that takes the four endpoints of the display as input and provide parameters for projective transformation of the captured image for different relative positions of the screen and the webcam.

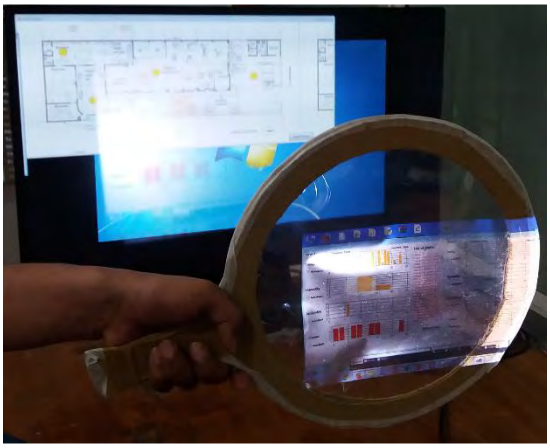


Figure 6. Proposed Visualization System

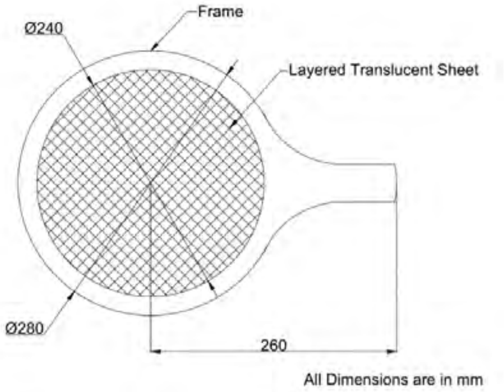


Figure 7. Schematic Diagram of the Projected Screen

Using a laser pointer as a computer mouse has already been explored by researchers but we conducted a controlled study to optimize the image processing algorithm and measured the laser pointer's performance for different illuminance described in section 5 below.

4.3 Early Warning System

The visualization module is integrated to an analytics and alert module that constantly analyses data recorded from sensors and set out an alert if any values cross a threshold. The user can send either a manual alert or set up an automatic alert for one, all or a subset of sensors using the graphical user interface provided with the visualization module. The alert is send as a Gmail to a pre-recorded email address. We chose Gmail as alert platform as sending a SMS requires the visualization module to be integrated with a telephone communication unit, while social networking messages (like Facebook or WhatsApp alert) require the end user to subscribe to a social networking site. The Gmail can be received on a smartphone or smartwatch. The Gmail message summarizes sensor readings and has a subject stating the type of sensor creating the alert.

5. EVALUATION

We have conducted two experiments to evaluate the proposed interactive visualization module.

- The first study explores different colour space and ambient illuminance to optimize the performance of the laser pointer based pointing device.
- The second study measures the legibility of the main and projected screens using a Pelli-Robson contrast sensitivity chart.

The following section describes the studies in details.

Study 1 – Optimizing Laser Pointer

Material: We used a 650nm, 5V, 5mW Laser light and a 19” Dell E1916HV display with 1280 × 800 pixel resolution. To capture the image of the red dot, we used a Microsoft LifeCam Studio Webcam with 320×240 pixel resolution.

Design: The camera was placed facing the display exactly at the centre at an angle 20° of inclination. The laser pointer is tied up to a tripod and is placed exactly perpendicular to the screen surface (fig 7).

Figure 8. Setup of Laser Pointer for Exposure Test

Initially two images were created in Matlab with one black background and another white background. Then a red spot was marked at a location on the image at a specific location (1023, 576). The laser pointer was then fixed rigidly such that it pointed the marked red spot on the screen. Now the screen was made fully black as well as fully white for displaying the two extreme conditions. The luminance of the room was set for 5 levels between 2 and 300 Lux by adjusting the lights, the brightness of the display screen was set for 6 levels between 10 and 60 Lux by adjusting the brightness manually and the exposure of the camera is set for 5 levels by adjusting it in a Matlab program. We collected one image for each combination of lighting condition and camera exposure value and in total 300 images were collected for both black as well as white backgrounds.

Results: We explored the following 7 different colour spaces to accurately detect the position of the red dot on screen.

RGB, HSV, YCbCr, YUV, HSL, XYZ, and GRAYSCALE. The error of the processed coordinates was calculated by taking the difference between the processed coordinate and the original coordinate. The time elapsed to process the coordinates is recorded for each image. Initially, the different components of each colour space models were analyzed for the errors to be less than 6 pixels both in X and Y axes. Some of the components in the spaces had huge errors and were not taken for comparison. The following components were considered for further analysis

- All components of RGB
- Value of HSV (HSV_V),
- Luma of YCbCr (YCbCr_Y),
- Luma and Chroma of YUV (YUV_Y),
- Luma of HSL (HSL_L),
- Saturation of HSL (HSL_S),
- All components of XYZ and
- Grayscale (GRAY).

We compared the number of correct selections and processing time for different components of the colour space model. It has been found that the Red component of RGB produced maximum number of correct selections of 214 out of 300 images undertaking least processing time (figures 9 & 10).

Discussion: Previous research mainly presented algorithm of detecting laser dot in the display but did not evaluate it with respect to range of illuminance and colour space models. Our study ensures that the laser pointer can be used to make a selection in less than 2 msec after highlighting between 2 and 30 Lux of ambient illuminance.

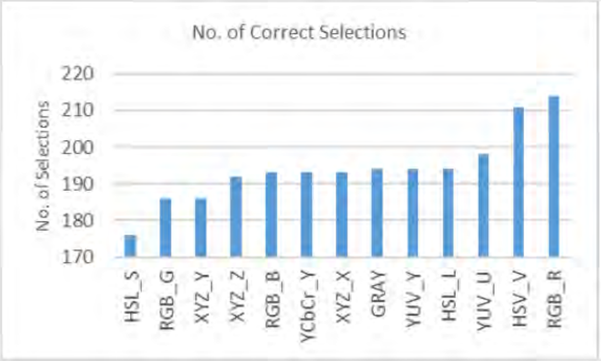


Figure 9. Number of Correct Selections of each Colour space components

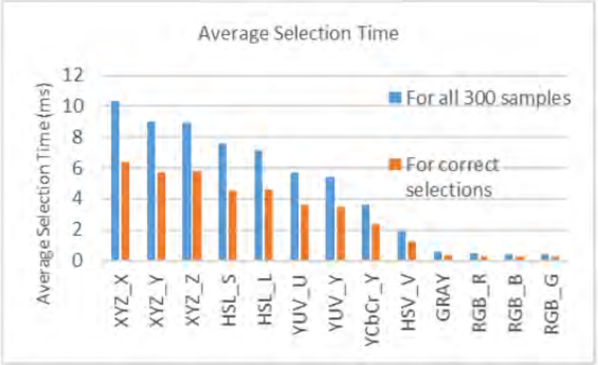


Figure 10. Average Selection Time of Colour space components

Study 2 –Legibility of Augmented Display

In this study, we checked if we put a projector on a screen then whether the screen remains legible and secondly whether the projected screen also remains legible.

Participants: We collected data from 10 participants who did not have any visual impairment.

Material: We used a 56 lumen Phillips pico – projector and a 27" Frameless LED Display with 1920 x 1080-pixel resolution. We used a 736 x 939-pixel resolution Pelli-Robson contrast sensitivity chart for comparing legibility.

Design & Procedure: The projector was placed 230 cm away from the main screen and focussed at 130 cm. initially we evaluated visual acuity of participants by asking them to read the chart at the main display without turning on the projector and only continued the trial if they could read the till the last character. Then we turned on the projector towards the screen and then requested participants to go through the chart and recorded the last character they read correctly. Finally, we hold the semi-transparent display at the focal plane of the projector and recorded again the last character participant could read correctly.

Results: We noted the number of lines and characters participants could not read on the contrast sensitivity chart. All participants can read the last line in the main display and the penultimate line in the projected display. On the main screen participants could not read 1.7 letter (stdev 1.4) of the last line on average and on the projected display 0.7 letter (stdev 1.34) of the penultimate line on average.

Discussion: This study evaluated how the perceived quality of an electronic display changes if another display is projected on top of it. The Pelli-Robson chart is a standard tool in ophthalmology to evaluate contrast sensitivity. We noted that there is marginal decrease in contrast for the electronic screen while the projected screen had even less contrast. This information will be used to develop new visualization interfaces for the next version of the system. However, the study shows that most users can read up to the half of the penultimate line of the Pelli-Robson chart, which is sufficient for legibility of most interfaces.

6. CONCLUSION

This paper presents detail on implementing a smart manufacturing set up with environment monitoring and posture tracking facility integrated with an augmented interactive visualization and Gmail based alert system. The set-up has been designed to minimize cost for ease of deployment by small and medium scale industry. Interactive features of the visualization module have been evaluated for different ambient light conditions and the underlying algorithms are optimized accordingly. Presently, the set-up is under deployment at a medium scale manufacturing industry.

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