ULTRA VIOLET IMAGING TRANSDUCER CONTROL OF A THERMAL SPRAYING ROBOT

D. Breen, E. Coyle and D. M. Kennedy
Faculty of Engineering, Dublin Institute of Technology, Dublin, Ireland

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Abstract: The thermal spraying industry has a global market of $1.3 billion. This industry relies heavily on manual operation of the thermal spraying equipment or in some cases, robotic systems that require costly set up of material for surface coating and time consuming trajectory planning. The main objective of this research was to investigate novel ideas for automating the thermal spraying process. This requires transducers that can provide information about arbitrarily shaped and orientated material for spraying and generating the trajectory plan for the robot manipulator during the thermal spraying process in real time. The most significant difficulty for any transducer, particularly low cost vision systems is the thermal spraying process which in our research is molten material such as aluminium in an Oxy-Acetylene flame with temperatures exceeding 3100^0C. This paper outlines the concept and based on the experimental results presented demonstrates combined optical and image processing techniques for obtaining information about objects behind a butane flame.

1 THERMAL SPRAYING ROBOT

1.1 Introduction

Thermal spraying robotic research is concerned with investigating a number of novel ideas, which will contribute to the autonomous control of an articulated thermal spraying robot manipulator. This control of the thermal spraying process, which is used in the application of wear, corrosion and thermal barrier surface coatings will improve safety, efficiency and costs in the surface coating industry.

Thermal spraying has an estimated global market of $1.3 billion dollars (AZoM). The operation of thermal spraying equipment requires the consideration of health and safety issues.

1.2 Health and Safety

In industrial applications, thermal-spraying equipment is normally enclosed in specialist enclosures designed to reduce noise, fumes and observation via safety equipment by operators from a safe location. R&D may not have these specialist enclosures. Therefore health and safety risks must be managed via appropriate health and safety equipment and procedures. Powder Flame spraying with an Oxy-Acetylene torch which is the system used in this research produces intense bright flames with a peak temperature in excess of $3{,}100^0$C.

Two-wire electric arc and plasma spraying systems produce UV-B and UV-C with their associated health and safety risks to the operator. Figure 1 shows a typical flame from the thermal spraying process.

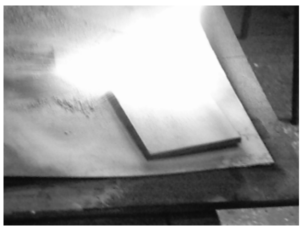

Figure 1: Thermal Spraying Process Flame.

The research presented in this paper uses UV-A lighting which is also present in the thermal spraying process.

1.3 Robot Control

The control of a robot manipulator requires information about the kinematics and dynamics of the robotic system being used for the thermal

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spraying system. Information about the position and orientation of the thermal spraying torch tip at different locations along the object to be sprayed and at different times which is known as trajectory planning is produced. This information is supplied into the robotic control system, which is used by the inverse kinematic equations and dynamic equations of motion to move the robot actuators to the desired locations. Thermal spraying automation provides this trajectory planning information via pre-programming for specific objects, which is time-consuming and costly.

The autonomous analysis of the position and orientation of the thermal-spraying torch, which would allow the spraying of unspecified objects at unspecified orientations, would significantly reduce set-up times and costs. However this level of automation is significantly hampered by the thermal spraying process. It is quite clear that the intense flame would hamper many object-measuring systems which could be used to obtain in real time, the position and orientation of the thermal spraying torch information. If however the flame could be removed from the scene and a low cost camera used to view the object with associated distance measuring techniques, this would accommodate the autonomous control of the thermal spraying process.

This research attempts to provide a possible solution to this difficult requirement.

2 FLAME REMOVAL

2.1 Ultra Violet Lighting

During the research on measuring the distance to objects with a low cost infra red laser and monochrome camera the problem of the thermal flame became a key issue. It was decided to investigate the use of a monochromatic light source and band pass filter to remove the thermal spraying flame. It was decided to use the UV-A spectrum (350 nm - 400 nm) as an initial area for research because it is reasonable to assume there is the full visible normal lighting (400 nm – 750 nm) and infra red (750 nm – 1 mm) in the thermal spraying scene and environment.

The light source used was a black light fluorescent lamp used in dance halls which has an amount of 387 nm wavelength light which matches our band pass filter.

2.2 Camera and Filter Spectral Response to Ultra Violet

A key aspect of the research was to use standard low cost equipment. The first objective was to ensure that the low cost monochrome camera has a response under ultra violet lighting, as the data sheet did not even provide data below 400 nm (Samsung). A 387 nm narrow band pass filter was used. Figure 2 shows the camera and filters relative spectral responses.

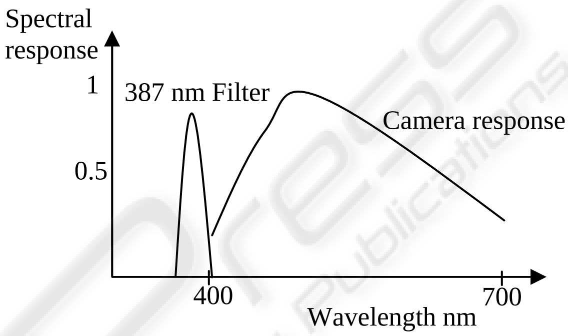

Figure 2: Camera and filter spectral response.

2.3 Ultra Violet Camera and Filter

A small piece of aluminium metal 50 mm x 60 mm with the letters D I T of height 15 mm written on it was used as a test piece. The test piece under internal daylight is shown in Figure 3. The test piece of aluminium with DIT and the background are clear and distinct.

Figure 3: Test piece of Aluminium.

A 387 nm filter was placed in front of the camera under internal daylight and the result is shown in Figure 4. The result shows a complete lack of response from the camera.

Figure 4: Camera response internal daylight and 387 nm filter.

A black light fluorescent lamp, which has a certain amount of 387 nm wavelength light, was then switched on and the cameras response is shown in Figure 5.

Figure 5: Camera response to filtered 387 nm lighting.

Due to the low intensity of 387 nm lighting, the camera was moved closer to the test piece. The background to the test piece is shown as dark stripes to the left and right of the image. The response of the camera clearly shows the letters D I T.

The monochrome image pixels have dynamic range values between 0 and 255. The response of the camera in this experiment provides a low dynamic range image. Using Matlab^{TM} this low dynamic range is shown quantitatively by its histogram in Figure 6. There are no intensity values between 185 and 255, however there is good separation between the letters DIT and the background shown by the dip in the histogram at an intensity value of 133.

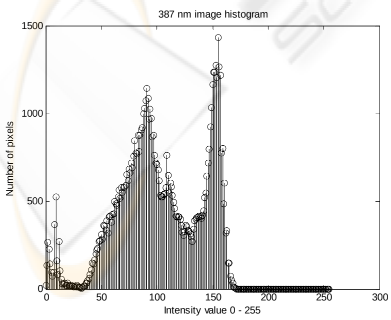

Figure 6: 387 nm image histogram.

The low dynamic range response is due not only to the response of the camera but from the lack of 387 nm intensity in the black light and the 387 nm filters attenuation effect.

2.4 Flame Removal from Image

Using a small butane lighter flame in front of the test piece under daylight lighting produces the image shown in Figure 7.

Figure 7: Daylight with flame.

Clearly image information behind the flame is completely obliterated because of the saturation effects of the flame on the cameras photo sensors, which is shown quantitatively in the images histogram in Figure 8.

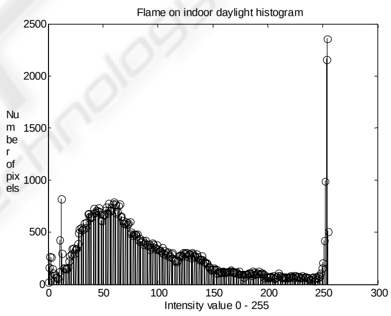

Figure 8: Flame on daylight histogram.

The histogram shows 8.2% of the pixels in the image have what we would consider saturated values between 250 and 255, which are caused by the butane flame. It would be extremely difficult to obtain information from behind the flame such as the area or centroid in pixels of the letter I in this image.

The main developments reported in this paper will detail a process for obtaining this and other information about the letter I, a process which could be developed and applied to the thermal spraying control process.

Placing the 387 nm filter in front of the camera and turning on the black light with the butane flame on produces the image shown in Figure 9.

Figure 9: 387 nm lighting flame on.

This technique was extremely encouraging, as the letters D I T are clearly visible. There is a slight transmission of flame intensity just above the letter I. Letters on the butane torch are also visible. Figure 10. is a histogram of the flame on in the 387nm image.

The histogram for the image shown in Figure 10 suggests this is a low contract image and there is considerable room for improving image information (contrast) above pixel value 185. This could be achieved by increasing the intensity of the 387 nm lighting source.

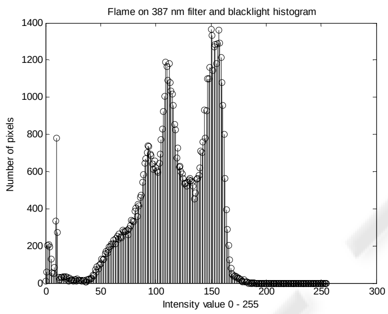

Figure 10: Flame on 387 nm image histogram.

3 IMAGE PROCESSING

3.1 Canny Edge Setection

Using the Matlab™ image processing toolbox the image in Figure 9 was processed using the canny edge detector with a Gaussian filter standard deviation value of 1.5 and high-low threshold values of 0.16 and 0.064 respectively which produced an edges image shown in Figure 11.

Figure 11: Edges image.

The edges image in Figure 11 was image processed further to remove the perimeter objects using the Matlab function `imclearborder` leaving only the letters D I T. Using the Matlab™ functions for labelling, selecting and infilling the letter I, `bwlabel`, `bwselect` and `imfill` the letter I was extracted as shown in Figure 12. For contrast the flame image is shown beside the extracted letter I

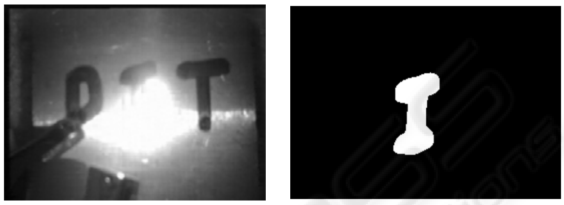

Figure 12: Flame on and extracted letter.

3.2 Feature Extraction

Using the Matlab™ image processing toolbox and the Matlab™ function `regionprops` a number of characteristics for the letter I were obtained. Some of these features are:

- Area 2561 pixels
- Centroid 131, 112 measured from top left corner
- Eccentricity 0.9148
- Orientation 83^0
- Perimeter 264 pixels

From analysis of the above, it is a straightforward process to obtain accurate real world values from image pixel values for actuating a robot manipulator using perspective transformations, inverse kinematics and camera calibration techniques.

4 THERMAL SPRAYING SPECTRA

4.1 Thermal Spraying Process

To determine the band pass filter and lighting wavelength for the removal of the thermal spraying flame and combustion material spectrum in the thermal spraying process would require extensive testing and the purchase of a range of filters. The reason for this is that there are a number of thermal spraying processes such as powder, arc, plasma and a vast range of surface coating materials all producing their own combustion spectra

The following is a list of some of the more common surface coating materials.

- Tungsten carbide/cobalt
- Chromium carbide/nickel chromium
- Aluminium bronze
- Copper nickel indium
- Hard alloys of iron

To apply this technique of using monochromatic ultra violet lighting and narrow band pass filter to remove the combustion process, theoretical research into the spectrum produced by the specific process where autonomous control would be beneficial is required. The reason for this is that the emission spectra of flames is sensitive to (Zirack):

- temperature
- gas/air or gas/oxygen mixture ratio
- gas purity
- burner type
- gas flow (laminar or turbulent)
- coating materials
- height of observation in the flame

Research can however provide reasonable indicators of a location for the band pass filter and where spectral problems may arise. The thermal spraying process used for this research was powder thermal spraying using an Oxy-Acetylene torch.

4.2 Oxy-Acetylene Flame

The Oxy-Acetylene flame is a chemical reaction resulting from the combination of acetylene C_2H_2 with oxygen 0_2. Figure 13 shows the two stages of the chemical reactions (Materials Engineering Group, MEG)

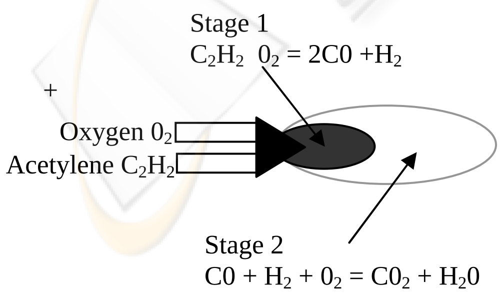

Figure 13: Oxy-Acetylene flame.

A neutral flame with products of combustion CO_2 and H_2O is produced with maximum heat output when equal quantities of oxygen and acetylene are used (MEG). Controlling this mixture would form part of the overall thermal spraying robot control system.

This is an idealised view and many other ordinary molecules and unstable radicals are produced in an Oxy-Acetylene flame in air.

4.3 Oxy-Acetylene Emission Spectra

The visible spectrum runs from 400 nm to 750 nm and the infra red spectrum runs from 750 nm to 1 mm (HyperPhysics). This suggests a portion of the ultra violet spectrum between 350 – 400 nm commonly known as the UV-A spectrum for the research as it excludes the visible and infra red spectrum.

Research is now concentrated on identifying weak spectra between 350 nm and 400 nm from the powder flame spraying Oxy-Acetylene in air flame with a range of molten surface coating materials, which is widely used in the powder spraying industry.

The ordinary molecules which are the stable products of combustion, H_20_2, $C0_2$, C0, 0_2 or N_2 in hydrogen flames do not provide spectra of any appreciable strength in the visible or ultra violet spectrum (Zirack).

The only product of combustion that may have an appreciable spectrum in the UV band is the hydroxyl radical OH which give band peaks at 281 nm 306 nm and 343 nm. Oxyacetylene flames not only produce spectra of hydrogen flames but also emit radiation of hydrocarbon radicals. Between the 350 nm and 400 nm wavelengths a weak CH band occurs at 387/9 nm and a strong band at 432 nm are found in air acetylene flames.

This suggests many wavelengths between 350 and 400 nm may be suitable for removing the Oxy-Acetylene flame in air but we must add the spectrum from the surface coating material to ensure there is no appreciable interference from the molten material in our chosen UV band. This is an area for continued research. However a review of published work by De Saro relating to emission spectra of molten elements such as aluminium and copper provides information on spectra of interest as follows:

- Aluminium 390 – 400 nm
- Iron 260 – 262 nm
- Magnesium 380 - 385 nm
- Copper 320 – 330 nm

Results so far suggest using a narrow band pass filter and lighting between 350 and 370 nm

In addition to the interference from the emission spectra, an added complication is the molten material itself. This will act as a dust cloud and have the effect of reducing contrast in the image.

The image processing techniques necessary for this research are those associated with low contrast images and reconstructing edges and shapes such as those provided by techniques like the Hough transform. (Young)

5 CONCLUSION

This paper has detailed a system of combining optical filtering and image processing which can be used to obtain information about low contrast objects behind or within a test butane flame.

The paper also suggests a region within the UV-A spectrum, which shows promise for implementing ultra violet image control of a thermal-spraying robot. Further work on identifying the spectra of a greater range of surface coating materials is required.

The ability to see through a flame could have benefits in other industries such as the fire fighting service and welding. The system detailed could be fitted as a single eye head up display or fitted to a small mobile robot where there are low smoke flame environments.

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