T-eye:

autonomous stuck scrap recognition in laser cutting process

R&A Team

Abstract

The aim of this paper is to develop a solution for quality check in laser cutting process on metal laminates. A preliminary introduction on the project and affiliated company is reported. Then the study focuses on the problem, causes and actual solution in the company.
The team has worked dealing with this roadmap: requirement analysis, possible solution analysis, technological(hardware) selection, code implementation and prototype assembly. The results are shown at the end of the paper, analysing critical issues and future improvement.

1. Introduction

This project results from a 6-month R&D project commissioned and sponsored by Efort – a leading manufacturer company in China – within the SEI Pioneer Programme framework, an Entrepreneurship & Innovation course on the development of an innovative deep-tech product starting from a challenge of a partner or institution, developed by School of Entrepreneurship & Innovation - SEI and Collège des Ingénieurs Italia; the project it is subject of a Non-Disclosure Agreement – NDA

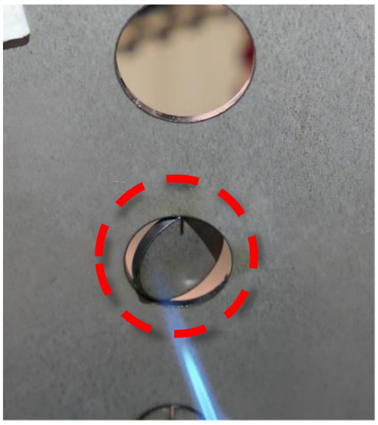
2. Problem

In laser cutting process, one of the main problems is the stuck scrap. The scrap is the element that has to be removed from a laminate in order to obtain the final piece. Usually the scrap falls down because of the gravity and of a little injector, near the laser tool, that pushes away the scrap using pressurized air.

Sometimes the scrap remains attached to the main laminated body due to:

- non-optimal laser cutting parameters, that tends not to have a proper cutting process so that some flaps are melted and remerged
- geometry and thickness of the scraps: "trying to fall", the scrap turns on itself and remains stuck to the rest of the piece

If the defect is discovered at the end of the production line, it will cost a lot to the company, following an exponential cost trend wrt the time.
The following is an example of stuck scrap



3. Current solution

Nowadays solution presupposes the presence of this defect. After the cutting process a human operator shakes the piece and removes all the scrap. Obviously, this is not an optimal solution because of the effort required from the operator, the time related to this "old style" method and the medical problems for the operator itself.

4. Requirements analysis

In order to draw up a proper requirement list, the company has been involved in a series of technical discussions to better understand the whole process and the related constraints. A clarification is now necessary: even if the current solution removes the defect, it's not required. What it's important it's that no defective laminates go on in the production line, so a quality checker that recognize defects is a good-enough solution in order to stop the defect and divide "good laminates" from "bad laminates". Following this approach, the fundamentals requirements that the solution must present are:

- autonomy
- high reliability
- easy integration
- scalable

The defect-check must be done in a not supervised way and has to be fast in order not to take time to the line. Moreover, it doesn't have to require a remapping of the process or the already present functional space. The scalability is necessary because it has to fit for different processing line and different object to check.

5. Possible solutions

Some solutions have been taken into account in order to fulfil the previously mentioned requirements. The study has been make looking for other companies approaches and experimental projects. Not all the solutions fit those requirements and it will be explained why, but in the interests of providing fuller information and showing the discarded ones, all of them will be presented:

- Motion detection
- Weight measurement
- Spark analysis
- IR emitter/receiver (Kinect)
- RGB camera
- Thermal Camera

Motion detection and **Weight measurement** have been discarded because of the "indirect info" that return. For example, one could predict the weight of the laminates after the process and estimate if there's an anomaly in the measured info but can't say where is it in the laminates. Additionally, it requires space, subtracted to the production line.

Spark analysis is a current approach that many companies implements in order to understand if the cutting parameters are well set. The problem is that an anomaly in the cutting process doesn't mean that there 'll be a stuck scrap. Furthermore, particular camera filters are required and the analysis in the processing chamber are difficult due to dust and extreme condition environment.

The **IR emitter/receiver** like Kinect is one of the best solutions adapt to those requirements: it's robust, fast and has small dimension so it's easy integrable. From the tool, a grid of IR is emitted. The receiver gets the reflected IR and analysing the distortion produced by the presence on the reflecting object can estimate a "depth map" .The negative points is that it has poor results when applied to metal surface because IR are non-well reflected especially by unvarnished metal surface.

Our solution merges the last two sensors the **RGB camera** and the **Thermal camera**. The analysis can be computed in a very fast way, after the cutting process. It's scalable, small and autonomous and nowadays this sensor has become popular for many different problems, to follow good methodologies and tips from other fields.

Why the thermal camera? When the laser cuts a piece, the metal is melted instantaneously because of the high-density power and with the pressurized air it's fast dripped through the hole just realized. Nevertheless, a small amount of the heat is absorbed by the scrap that is considerable hotter than the rest of the piece. This way you can analyse the temperature in order to check if residual is still in the piece.

6. Technological selection

Selecting a suitable product, three main criteria has been considered:

- price
- community usage and development
- performance

Besides sensors, the team has decided to work on a very popular pc for experimental project: the “Raspberry PI”. The model used is the “Raspberry PI 3B”. It has low price and guarantees many accessories and compatible sensors.

Starting from this point, the “PI Cam V2” has been selected as RGB Camera. With its 8 MPs has a good enough resolution for our purpose. Moreover, it’s very easy to use and numerous projects can help with its integration in the code.

The situation is different for the thermal camera: the sensor is more expensive with respect to the performance and it’s not a so commercial product. Our decision ended up with the “Pimoroni MLX90640“ with 55° v.a. It’s a thermal sensor from Melexis with a 24x32 resolution, mounted on a Pimoroni development card.

The hardware is:

- Raspberry PI 3 Model B +Dissipator

- Pi Cam V2

- Pimoroni MLX90640 55°

- Related accessories

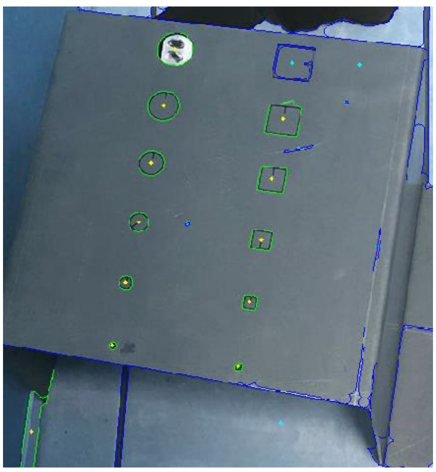
7. Code implementation

The code has been implemented, testing it on a metal laminates provided by Efort. It presents manually removable stuck scrap:

The code has been written in python language, through “Anaconda”, popular tool that simplifies package management and deployment. “Open CV” has been the image processing library used, because it’s very powerful, with a lot of integrated functions and a vast community.

For sake of simplicity, the code has been developed on a pc, getting picture from a mobile and then exported and completed on Raspberry.

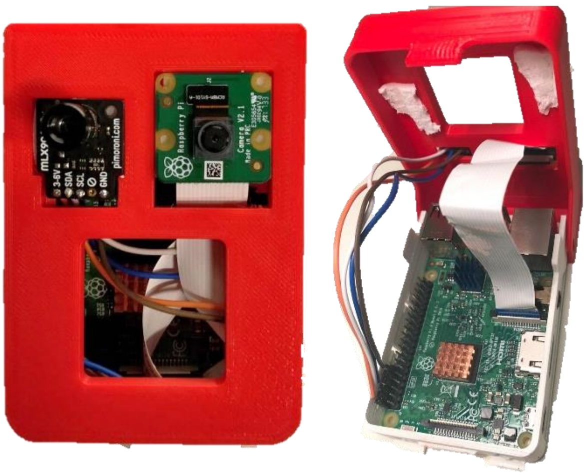
The following is a minimal explanation on how it works:
when the program starts, rgb and thermal images are acquired in loop. Through a Canny filter a binary mask of contours is produced trying to reject all those contours not related to the laser cutting process (for ex. superficial defects or light reflection). The mask contour accuracy is then improved with a "closing function". Next, all the contours are recognized as points connected by lines, through a library function, and storage in an array. Now, this is the core part of the code: each contour is analysed and passed through a "test function" to remove the "false positive contours" that the Canny filters bounds didn't remove. After this, the program estimates the centroid of the contour with "image moments" and scale the contour x1.2 and x0.5, creating an external and internal contour. The median red value of the pixels of those two contours are extrapolated. If they're similar it means that there is metal inside the contour as outside and the scrap is stuck in, otherwise the code starts to check another contour. If the first check ends with a "stuck scrap" a second check is involved: the program match the centroid in the thermal image through the coordinates of the centroid, scaled by some factor and get the temperature value of that point. If the point is higher than a threshold value, it's assumed that the scrap is stuck with high probability. For those elements that are assumed "stuck scrap" only for the first check, they are still considered as defective but with lower probability. This sequence of checks is done for every contour till no contour has to be checked. The program then shows the response graphically:



In the appendix of the paper there is a flowchart to better understand the code.

8. Prototype assembly

For the purpose of creating a small and easy to integrate device a suitable case has been designed and printed with a 3D printer. The case presents a compartment for raspberry and two frontal recess for the cameras. The focal lens centres of the cameras have been designed horizontally collinear so as to simplifies the points matching:



9. Result

The final product shows a really good performance in terms of speed: it requires 0.8s to perform a complete analysis. It's small and doesn't need other accessories. It has to be improved in terms on robustness, reaching an accuracy of 70% at the most but only in certain condition. However, it is suitable starting point for a future work. Some improvement will be discussed in the section "Future improvements" .

10. Critical issues

The main critical issue is related to a non-structured environment: the algorithm parameters are referred to certain operational conditions. In this paper the team has decided to work with a distance from the object of 1.5 meters and a diffuse light to avoid “shining effect” on the surface. Moreover, even the shape of the object and of the scrap is a factor of uncertainty. If the code has to deal with many op. conditions, many parameters settings has to be introduced. This approach is not optimal, creating complexity in the code because it is a sort of research of many local minima of virtual cost function(each parameters setting represents that minima).

Another problem is related to the thermal camera low resolution: the matching from rgb point to thermal point it’s difficult if the object is far from the thermal camera that can’t distinguish in a proper way nearby points.

11. Future Improvements

A well-known and current solution, in order to overcome the “local minima research” mentioned in the Critical issue section, is to develop a deep learning algorithm, pointing on autonomous object detection. Thanks to this type of solution it’s possible to instruct the neural network with many pictures of the scrap in different conditions of light, shapes and distance so that it can generalize the object research and reach higher accuracy. A first attempt has been developed in this project showing good results. The main drawback is the computational cost of this approach. Due to this, we preferred continue to work on an “old style” image processing way, even because the difficulty to export on raspberry, but it’s for sure the right way for a future improvement.

Another possible implementation is to create a double info-direction: from rgb→thermal (as in this paper) and from thermal→rgb looking for thermal anomaly and analyse that point on a rgb image. With this approach a high-resolution thermal camera is required.

Appendix

Code flowchart :