Polarization image sensor-based laser scanner for reflective metals: architecture and implementation

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***Abstract*—Laser scanners are essential for many industrial applications such as inspection, metrology, assembly, and welding. Laser scanners are especially interesting in robotic welding to determine the shape and position of the welding groove. There is a wide range of commercial laser scanners available in the market, still, they exhibit some limitations when scanning reflective metals like aluminium, which poses a challenge when laser scanners are used for robotic welding of aluminium. In this paper, a novel laser scanning solution is presented based on a polarization image sensor, which minimizes unwanted reflections when scanning metallic surfaces. The hardware and software architectures are detailed in the paper. The proposed system is validated in experiments with the aluminium alloy 6082 where the system is able to detect the shape of a laser profile with higher precision than a standard image sensor-based laser scanner.**

***Index Terms*—polarization sensor, laser scanning, reflective metals scanning, aluminium scanning**

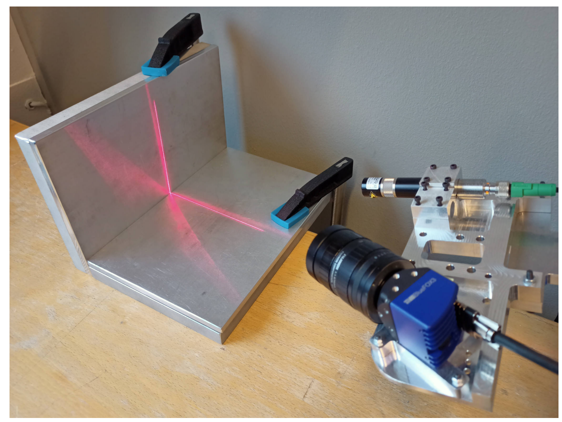


Fig. 2: Prototype implementation

I. INTRODUCTION

Structured light systems are based on two main components: a light source and a photodetector. The current trend in the industry and the research community [1, 2] is to use a laser projector as a light source with different possible patterns in combination with an image sensor. Sensor systems that use structured laser light as its light source are a well established solution in sectors such as automation or industrial robotics. One of the primary applications in the robotic vision industry are sensor systems based on the laser light section method [3] which allows for the measurement of contours and profiles by projecting a laser line on the surface of the object and then use an image sensor to capture it.

There are many challenges for these laser scanning systems that may arise in an industrial environment because of several different types of noise and disturbances like ambient light, welding sparks, deformations due to changes in temperature, bad machining or spurious reflections and interreflections on the surface of metals.

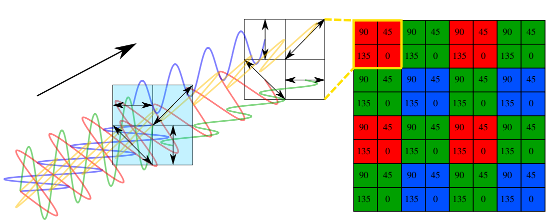


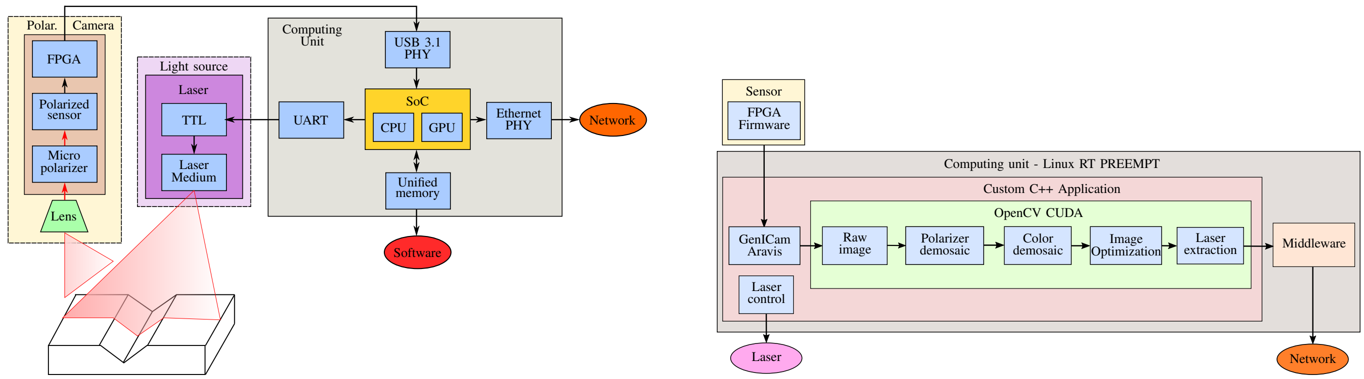
Fig. 1: Super pixel array configuration as found in the color version of the polarization image sensor

Several approaches that can overcome some of these problems have been presented in previous works: Stereo camera setups [4, 5], High Dynamic Range imaging [6] or more related to this work, polarization [7, 8]. But their requirements might not make them suitable for most applications as they may need a bulky setup with several sensors, special optics, heavy processing or they are challenging to implement in real-time. In the presented work we propose a new laser scanning solution that is implemented with a single sensor that is compatible with standard light sources and lenses, and which runs in real-time. The photodetector of the proposed system is based on the Polarsense polarization image sensors family recently released by Sony [9].

The paper presents the polarization sensor principles, the hardware and software solutions, and a validation experiment where the intersection of two plates in the aluminium alloy 6082 was found with higher precision that with standard laser scanning systems.

II. POLARIZATION IMAGE SENSOR

Polarization refers to the properties of the light in the transverse plane to the direction of light propagation in which the electric and magnetic fields oscillate [10]. It is not visible for humans or measurable using a standard image sensor



(a) Hardware architecture

(b) Software architecture

Fig. 3: Hardware and software architectures

(without a polarizer). The IMX250MYR [9] image sensor is a color polarizer filter array (CPFA) image sensor which implements two filter arrays: a color filter array (CFA) and a polarizer filter array (PFA). The polarizers used in this sensor are called wired grid polarizers and they block (by reflection) the polarization parallel to the wire direction while they transmit the polarization normal to the wire direction [11]. A representation of these polarizers and the super pixel array configuration can be seen in Fig. 1.

In every raw image (Fig. 4a) captured with a color polarization image sensor there are 12 different channels: 3 color channels (red, green and blue) and 4 linearly polarized channels (0°, 45°, 90° and 135°) for each color channel (Fig. 4b). The process of recovering the color information is called CFA demosaicing [12] and the process of recovering the polarizer information is called PFA demosaicing [13].

III. Proposed System Architecture

A. Hardware architecture

The first key component of the hardware architecture (Fig. 3a) is a polarization camera that integrates a Sony CMOS (Complementary Metal-Oxide-Semiconductor) image sensor with a micro-polarizer layer (Fig. 1) together with an FPGA (Field Programmable Gate Array) for the low-level processing and a camera lens. The polarization camera is connected to the computing unit using the USB3 Vision interface which makes use of the GenICam (Generic Interface for Cameras) protocol [14]. For the light source, a Powell lens [15] laser line projector that generates a uniform (non-Gaussian) laser beam is used. The projector is connected to the computing unit using the UART (Universal Asynchronous Receiver-Transmitter) protocol and its laser medium is controlled using TTL (Transistor-to-Transistor Logic). The hardware architecture is built around a computing unit, which main component is an SoC (System on a Chip) that integrates a Central Processing Unit (CPU) and a Graphics Processing Unit (GPU) for tasks that can be highly parallelized (i.e. image processing). The CPU and GPU memory is unified in one memory stack. Additionally, the computing unit implements an Ethernet controller that is used for communicating with the network.

Algorithm 1 Polarized laser image pipeline

Input: Raw sensor image I_{raw}

Output: Position of the laser in image coordinates

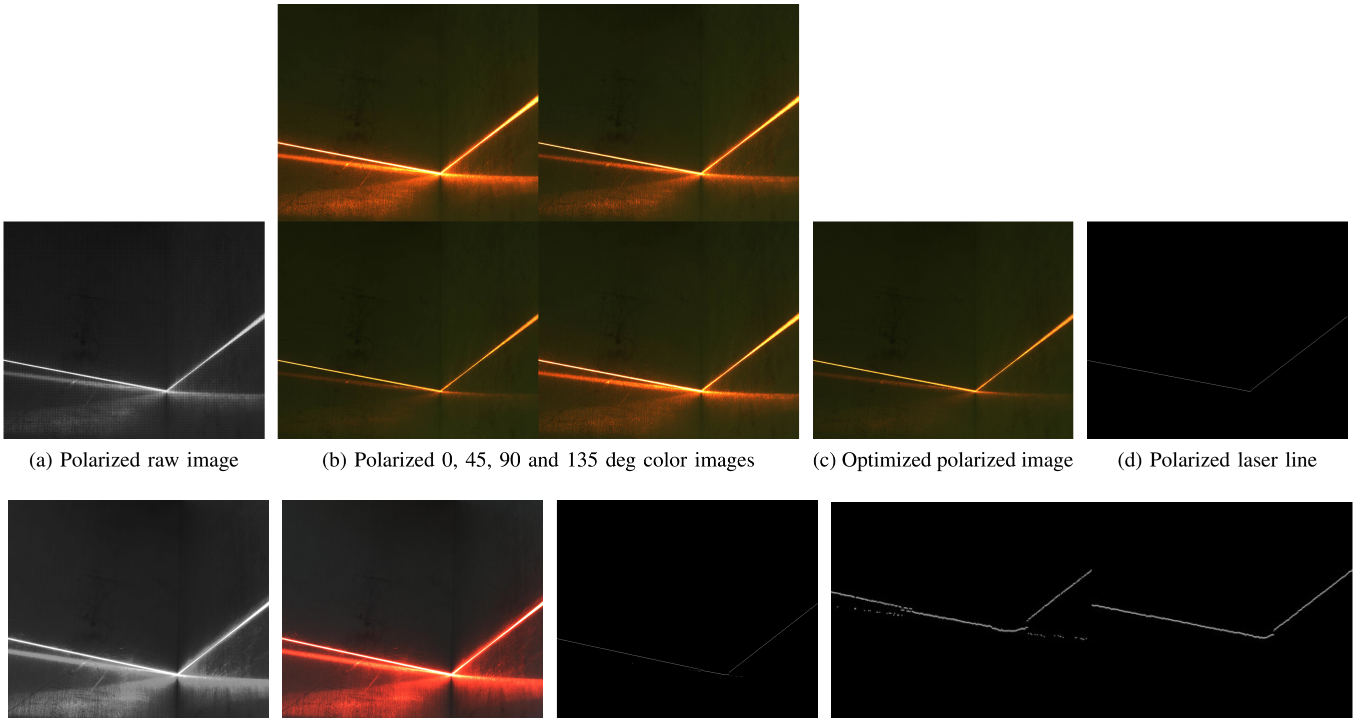
procedure POLARLAS(I_{raw})
- $(I_{0^\circ}, I_{45^\circ}, I_{90^\circ}, I_{135^\circ}) \leftarrow PFA_{dem}(I_{raw})$ ▷ Pol. dem.
- $I_{opt} \leftarrow OptPolar(I_{0^\circ}, I_{45^\circ}, I_{90^\circ}, I_{135^\circ})$ ▷ Optimize
- $I_{opt} \leftarrow CFA_{dem}(I_{opt})$ ▷ Color demosaic
- $I_{opt} \leftarrow ToMono(I_{opt})$ ▷ Convert to monochrome
- $I_{opt} \leftarrow Thresh(I_{opt})$ ▷ Apply a threshold
- **for** every column in I_{opt} **do** ▷ Laser line extraction
  - $P_C \leftarrow P_L$ ▷ Position of the laser in the column
- **return** $LaserCoordImg$ ▷ Output is 1 image

B. Software architecture

The main application of the software architecture (Fig. 3b) which runs on the computing unit, coordinates the different tasks and is written in C++. Its first task is communicating with the FPGA firmware using the GenICam protocol, in order to start, stop, and configure the image acquisition, in addition to retrieving the actual image data. Inside the application, the camera firmware is accessible via its USB3 Vision interface using the GenICam protocol through the open-source library Aravis [16]. For the image processing part of the application, the OpenCV library, which has GPU acceleration capabilities, is used to compute the pipeline in Algorithm 1. This pipeline can be summed up as acquiring the raw image, performing the PFA demosaicing, performing the CFA demosaicing, creating the optimized image by combining the data of the 4 polarized color images and performing the laser line extraction. Furthermore, the custom application has to control the laser, which is a simple function to turn it on/off or change its intensity. In addition to communicating with the network by means of a middleware solution.

IV. Implementation

The proposed architecture was implemented as a prototype (Fig. 2). The polarization camera used is a MATRIX VISION mvBlueFOX3-2051pC that integrates a Sony IMX250MYR



(a) Polarized raw image (b) Polarized 0, 45, 90 and 135 deg color images (c) Optimized polarized image (d) Polarized laser line

(e) Standard raw image (f) Standard color image (g) Standard laser line (h) Zoomed in standard (left) and polarized (right) laser lines

Fig. 4: Comparison between the polarization image sensor and the standard image sensor images

5.07 Megapixels color capable polarization image sensor. For comparison purposes, an OMRON STC-MCS500U3V camera that integrates a Sony IMX264LLR 5.07 Megapixels color capable non-polarized image sensor was used. This standard model of the Sony IMX family was chosen because of its similarity with the IMX250MYR sensor integrated in the polarization camera. Regarding the optics, the same C-Mount FUJINON $1 : 1.4/16$ mm CF16 lens was used for both cameras. For the laser projector, a Z-LASER Z25M18S3-F-640-LP45 operating at 640 nm and displaying a single line was chosen. The proposed image pipeline in Algorithm 1 was implemented in a `C++` application running in the Linux4Tegra operating system with a Real-Time kernel. Furthermore, it was running on an Nvidia Jetson AGX Xavier that is based on an SoC that integrates an ARM CPU plus an Nvidia GPU.

V. Experiments and Results

The plates scanned in the experiments were made of aluminium alloy 6082. The alloy was chosen because it is highly reflective [17] and widely used [18]. With regard to the geometry of the experiment, the two aluminium plates were arranged in a corner joint configuration forming a right angle and then firmly clamped, as it can be seen in Fig. 2. The distance from the laser projector to the joint is approximately 30 cm. The results with both sensors are shown in Fig. 4. Note that the optimized polarized image in Fig. 4c displays a substantial reduction in the amount of reflections with respect to the standard color image in Fig. 4f. And, as an outcome, the shape of the extracted laser line when using the polarized image sensor in Fig. 4d is closer to the real shape of the laser and contains less artifacts when compared to the extracted laser line when using the standard image sensor in Fig. 4g. The benefits of using the polarization image sensor are even more noticeable if the area around the joint is zoomed in as it can be seen in Fig. 4h, where the standard image sensor struggles to detect the real shape of the laser in certain parts of the profile, generating artifacts in the image, in addition to deforming the shape of the corner. Meanwhile, the polarized image sensor manages to detect most of the laser profile correctly, with only 4 pixels of a tiny area of the profile not detected properly.

VI. Conclusions

As the results show, under similar circumstances (same image sensor family, laser projector, lens, and hardware and software platforms), the proposed novel laser scanner based on a polarization image sensor can detect the shape of a laser profile in a more precise way than a standard image sensor can when scanning very reflective aluminium alloys. Although there are some limitations in areas containing great amounts of specular reflections. We believe that these results are especially interesting for robotics applications like industrial robotic welding, where measuring the accurate position of the corners or joints of the scanned metallic plates is essential.

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