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PhoXi® 3D Camera

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Description of the innovation:

General description

Photoneo's brand new PhoXi® 3D Camera is the highest resolution and highest accuracy area based 3D camera in the world. The camera can capture accurate point-clouds combined with standard intensity image of the target. It it based on Photoneo's patented technology called Parallel Structured Light implemented by a custom CMOS image sensor. The novel approach brings a unique set of traits that makes it the most efficient technology for high resolution scanning in motion and thus making the PhoXi® 3D Camera the best close and mid-range 3D camera on the market.

The key benefits of the Parallel Structured Light:

1. Scanning in a rapid motion - one frame acquisition, 40 m/s motion possible
2. 10 times higher resolution & accuracy than competing technologies - more efficient depth coding technique with true, per pixel measurement
3. No motion blur - 10 µs per pixel exposure time
4. Rapid acquisition of 1068 x 800 point-clouds up to 60 fps
5. Outdoor operation under direct sunlight - patent pending technology of active ambient light rejection
6. Interreflection suppression - active ambient light rejection
7. Multiple devices operational simultaneously at the same space

More details about the benefits can be found in the technical details fraction.

A carbon fiber body of the camera ensures the same level of rigidity possessed by PhoXi® 3D Scanners and is lightweight. The PhoXi® 3D Camera consists of three components: camera unit equipped with our custom Mosaic Shutter CMOS image sensor, laser projection unit and GPU equipped processing unit that serves as a brain for smart applications. You can have a look at the Camera mounted on a robot in the figure 1.

Comparison to other approaches

There are numerous 3D area sensing techniques available on the market. All of these approaches can be divided into two main categories.

1. For scanning static only scenes
2. For scanning static and dynamic scenes

The main technology driver in the first category is a sequential structured light used in many meteorological applications. Photoneo's line of PhoXi® 3D Scanners is a well adapted representant of this category. Due to the sequential (multi frame) capturing, this technique is not suitable for dynamic scenes. The Parallel Structured Light is derived from this segment.

The main challenge of 3D scanning in motion consists in the necessity to capture consistent data in one frame. Every category solves the problem in a different way which typically involves trade-offs. You can find an overview of the approaches together with typical representants in the figure 2.

Time-of-flight

Time-of-flight measures the time light takes from a source of the illumination to a scene and back. The main challenge here is the speed of light itself. The time is typically measured by measuring the phase shift of a modulated signal. To satisfy a decent depth accuracy, high pixel modulation frequencies have to be applied. The main limitation here is the physics itself, as the higher frequency means an insufficient charge transfer and thus a worse contrast and SNR. The limitation directly implies a level of accuracy achievable by TOF systems. It is typically in the level of centimeters. Interreflections are also a problem, and they can bend the surface dramatically.

Active stereo

Active stereo solves the unreliability of passive stereo by projecting an artificial texture to an object. Despite of that, it still needs to solve a computationally intensive problem of image correspondence matching. The projected texture can be either a high frequency texture, that can satisfy a higher resolution but typically with a poor reliability (because the matching problem is more complex) or a low frequency texture (random laser dots are usually used) that can offer a higher reliability but with a poor resolution (the features are sparse).

Structured patterns / dots

Structured patterns/ dots technology uses a spatially encoded pattern that encodes depth disparity information into patches of the pattern (typically projected through a laser diffraction grating in a form of well designed dot collection). In order to correctly capture the depth information, the camera needs to see enough of the patch to be able to reconstruct the coding. This creates artefacts on small objects and edges of the surfaces. Due to the Nyquist-Shannon theorem, to reconstruct individual dots in the projection (and thus 3D measurements), one needs an order of magnitude higher camera resolution. State-of-the-art systems can produce around 70k 3D points, using around 25 camera pixels for one 3D measurement.

Parallel Structured Light

Parallel Structured Light uses a clever sensor design to parallelize the sequential structured light, allowing it to capture the scene lit by different patterns at the exact same time. It shares most of the advantages of the sequential structured light like resolution and level of accuracy, but, in addition, solves one of its biggest limitations - the ability to capture a dynamic environment.

A typical performance of the products using all techniques can be found in the figure 3.

Outputs

To get a better overview of the technology, please have a look at the attached video that consists of several slides and camera outputs:
https://www.youtube.com/watch?v=Z7mOBj-9g0Q&feature=youtu.be

Here you can witness outputs of our PhoXi® 3D Camera recording with the web 3D video viewer we have created (pls rotate/zoom etc.; with mobile devices, the experience is limited):

Guitar lady - http://photoneo.com/videos3D/index.php?GuitarSolo
Bass guitar solo (check the strings!) - http://photoneo.com/videos3D/index.php?BassGuitarSolo
Rotating fan - http://photoneo.com/videos3D/index.php?FanScene

(In case it's not working properly, please visit our YouTube channel:
Guitar lady - https://youtu.be/HOnQFhkQNaI
Rotating fan - https://youtu.be/r3EgpO9ED7Y

The point-cloud captured in one frame camera mode can be found here: https://skfb.ly/6AwQM
The point-cloud captured in multi frame scanner mode can be found here: https://skfb.ly/6AwOD

Technical details and advantages of the innovation:

Advantages of sequential structured light

Typical sequential structured light system uses several projection patterns to encode spatial information to the scene. This method is known for its high data density and speed of measurements, and is widely used in metrology. The main disadvantage of the technology is a lack of possibility to scan objects in motion, or to scan while the scanning device itself is moving. The only possible way to overcome the aforementioned disadvantage of 3D sensing based on the sequential structured light is to capture all the data at the same time, and produce a consistent measurement not affected by the movement.

Parallel Structured Light

Photoneo's Parallel Structured Light overcomes the limitation by projecting and capturing multiple encoded patterns at the same time. This is done by using pixel modulations inside our custom CMOS sensor. The sensor itself is divided into several groups of individually modulated pixels. These groups are controlled by a control unit, that work synchronously with the projection. Instead of modulating the projection itself, the coded patterns are injected into the groups. At the end of the frame, the sensor can produce more than 20 different virtual images of the scene lit by injected the coded patterns. The technique is general and can use any kind of patterns conventionally used for sequential structured light and change it on the fly to adapt to different materials and light situation.

These virtual images are then processed in embedded processing to final results, delivered to a client's computer over gigabit ethernet. The sensor provides 3 kinds of outputs:

1. Point Cloud - 32 bit per channel XYZ
2. Normal Map - 32 bit per channel XYZ
3. Texture - 10 / 12 bit Grayscale

In the "one frame" camera mode, the sensor provides 1068 x 800 resolution outputs. These points are interpolated from ~ 500k individual measurements. The typical standard deviation of z-noise at 1 m distance is below 0.5 mm (key benefit 1). The pixel design ensures that all photons contribute to the 3D measurement in an optimal way. The efficiency of using just 4.5 pixels per 3D measurement with sub-pixel accuracy coding (high z-accuracy) gives the technology an advantage over the competition and offer the highest XYZ resolution (key benefit 2).

The other mode of operation is a so-called scanner mode designed for static scenes. In this mode, the sensor returns its raw sensoric output of 1602 x 1200 individual measurements. This is captured in 3 subsequent frames (
The projection unit lits the scene with a laser deflected by a mirror. The per pixel exposure of the projection is just 10 μs, which can ensure motion blur-free, consistent data (key benefit 4).

Active ambient light rejection

All of the area based 3D sensors share a common challenge of operating under direct sunlight. The direct sunlight can deliver up to 1120 W / m2. All Photoneo's sensors are equipped with high-end band-pass filter that reduces the ambient light to a level of about 15 W / m2. This still outperforms most of the projection systems and can oversaturate the image, or cause a strong shot-noise.

One of the possibilities to decrease the effect of ambient light is to deliver active illumination as a short pulse, increasing the optical power output of the projection and decreasing the overall exposure time of the system. With this approach, there are limitations in parts availability, complex power supply management, eye safety hazard or heat management issues.

Photoneo's patent pending Active ambient light suppression is able to work in sync with the projection and the sensor to control the light sensitivity of the sensor surface. In any single time during the acquisition, because of geometrical restrictions, only about 1 percent of the sensor surface can possibly be exposed by the direct reflection of the projection. The camera's control circuit can disable the rest of the sensor (99%), so it does not collect any photoelectrons. The technology effectively suppresses the ambient light of any source by a ratio of 1:100 and thus allows scanning under the direct sunlight (key benefit 5).

The same technology suppresses also internal interreflections between pixels by the same ratio 1:100 (key benefit 6). When two sensors works simultaneously in the same area, the technique rejects second scanner projection in 99 % of the image, with just 1 % of pixels affected by the second scanner's projection. These pixels can be easily identified and filtered from the result (key benefit 7).

Relevance and application possibilities of the described innovation for the machine vision industry:
The level of detail captured by the PhoXi® 3D Camera is sufficient to capture individual submillimeter details of the man-made world, while its ability to scan objects in rapid motion allows it to be used in almost any situation. Majority of machine vision solutions would benefit from out-of-the-box 3D information but due to the lack of resolution and accuracy of 3D cameras, developers of vision systems have had to prefer custom multi-camera 2D based solutions, increasing development and integration time heavily. Photoneo's ready to be used 3D Camera and universal 3D software packages for object identification, 6D position detection, tracking and recognition makes the development of generic solutions much easier. Better underlying data shorten training time and execution of Machine Learning algorithms, and help to focus on relevant data without unnecessary artificial augmentations.

In recent years, 3D sensors have opened new opportunities and brought new applications, and we humbly believe that we can contribute to this trend of a continuous advancement of the machine vision industry:

o Bin picking - We see a very strong traction in automotive, general manufacturing and logistics for e-commerce order fulfillment
o Palletizing, depalletizing, machine tending - Improved reliability helps to handle smaller and sensitive objects/parts
o Online quality control and metrology - Potentially one of the largest topics in machine vision
o Autonomous delivery systems - Industrial vision guided vehicles, drones

o People counting, behaviour monitoring - VR, AR and ergonomy
o Object sorting - Food processing and waste sorting
o Reliable face recognition - High resolution and accuracy allows to cover a large area
o Safety systems - Complementing Lidar based systems
o Harvesting - Efficient non-destructive harvesting and other processes in agriculture

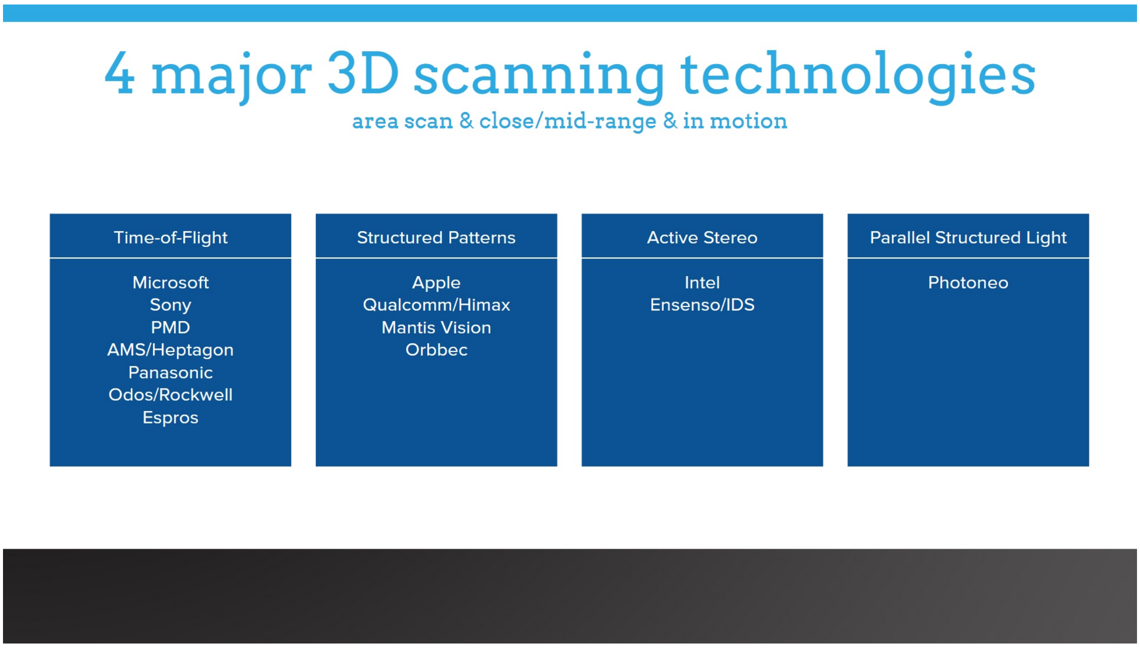
We believe the PhoXi® 3D Camera can help to create flexible automation lines that can work without fixtures and can adapt and be reused to different products manufactured by the same line. We believe that it is crucial to satisfy the efficient Industry 4.0 with its smart connected factory, and provide an alternative to production relocation caused by ever increasing wages.

Video:
https://www.youtube.com/watch?v=Z7mOBj-9g0Q&feature=youtu.be

Images:
38686_figure_1.jpg
38686_figure_2.jpg
38686_figure_3.jpg
38686_figure_4.jpg

38686_figure_1.jpg

38686_figure_2.jpg



38686_figure_3.jpg

extrapolation

		Output / Sensor resolution	True resolution	Z noise @ 1m, 50% albedo
Consumer ???	Active stereo Correlation	1280 × 800	~**5 000** projector dots (+features from passive stereo)	3mm
Industrial ???	Active stereo Correlation	1280 x 1024	512 x 410 = **~210 000** (Nyquist-Shannon sampling theorem)	3mm
Consumer ???	Structured dots Recognition	640 × 480	~**70 000** projector dots	3mm
Consumer ???	Time-of-Flight	512 × 424	256 × 212 = ~**54 000** (0.5x penalty - heavy spatial smoothing)	3mm
Consumer ???	Time-of-Flight	160 × 120	160 × 120 = ~**19 000**	3mm
Industrial ???	Time-of-Flight	640 × 480	320 × 240 = ~**77 000** (0.5x penalty - heavy spatial smoothing)	6mm
Consumer ???	Time-of-Flight	640 × 480	640 × 480 = ~**300 000**	6mm
Industrial ???	Time-of-Flight	640 x 480	640 × 480 = ~**300 000**	10mm
Photoneo	Parallel structured light	1068 × 800 (One shot mode)	**~500 000**	0.5mm

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