Snorkelling between the stars:

submarine methods for astronomical observations.

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INTRODUCTION

Trying to reach diffraction-limited astronomical observations from ground-based telescopes is very challenging due to the atmospheric effects contributing to a general blurring of the images. However, astronomy is not the only science facing turbulence problems; obtaining quality images of the undersea world is as ambitious as it is on the sky. One of the solutions contemplated to reach high-resolution images is the use of multiple frames of the same target, known as fusion super-resolution, which is the principle for Lucky Imaging. Here we present the successful result of joining efforts between the undersea and the astronomical research done at the Canary Islands.

METHOD

The algorithm to improve the spatial resolution using Super-Resolution (SR) applied to Multi-Camera (MC) systems and dynamic imaging has been developed by the Diseño de Sistemas Integrados (DSI) division at the Instituto Universitario de Microelectrónica Aplicada (IUMA) from Universidad de Las Palmas de Gran Canaria (ULPGC), in collaboration with PLataforma Oceánica de CANarias, (PLOCAN).

Fig.1: Frame extracted from a submarine video. Left: interpolation applied (showing pixelation). Right: MACABM Super Resolution method applied.

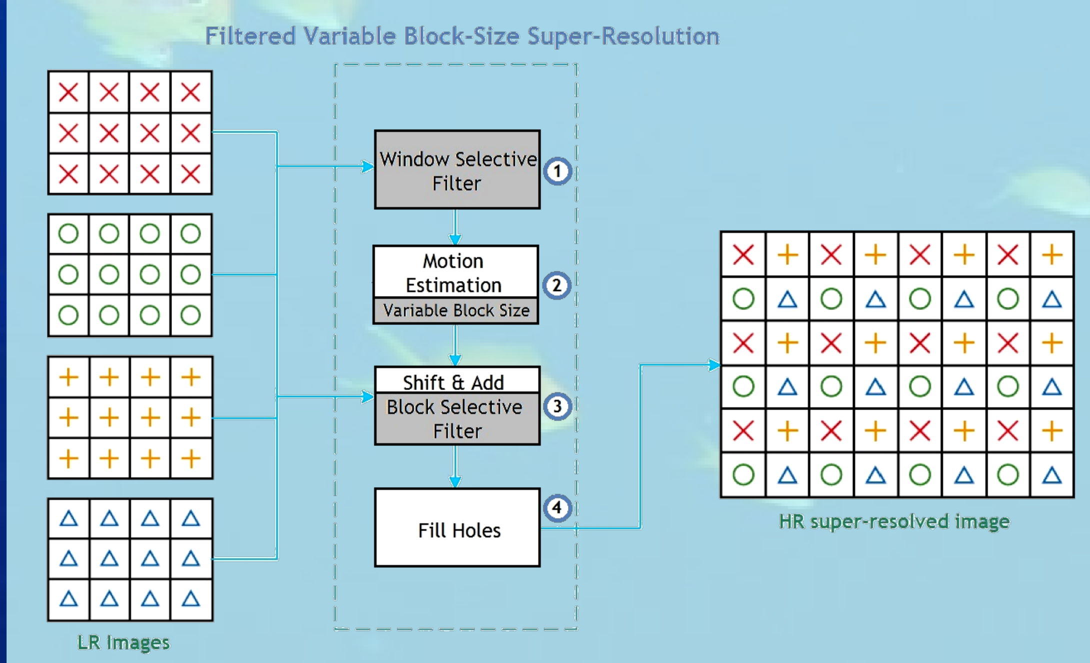


Fig.2: Dynamic SR algorithm block diagram.

The SR algorithm consists on:

- **Preprocessing:** in this step the information is selected.
- **Multicamera SR:** Based on the overlapping between cameras.
- **Selection filter:** To select some specific frames and macro-blocks from the sample.

The SR algorithm is run on every frame in the sequence and can be done in real time even under a fast frame rate.

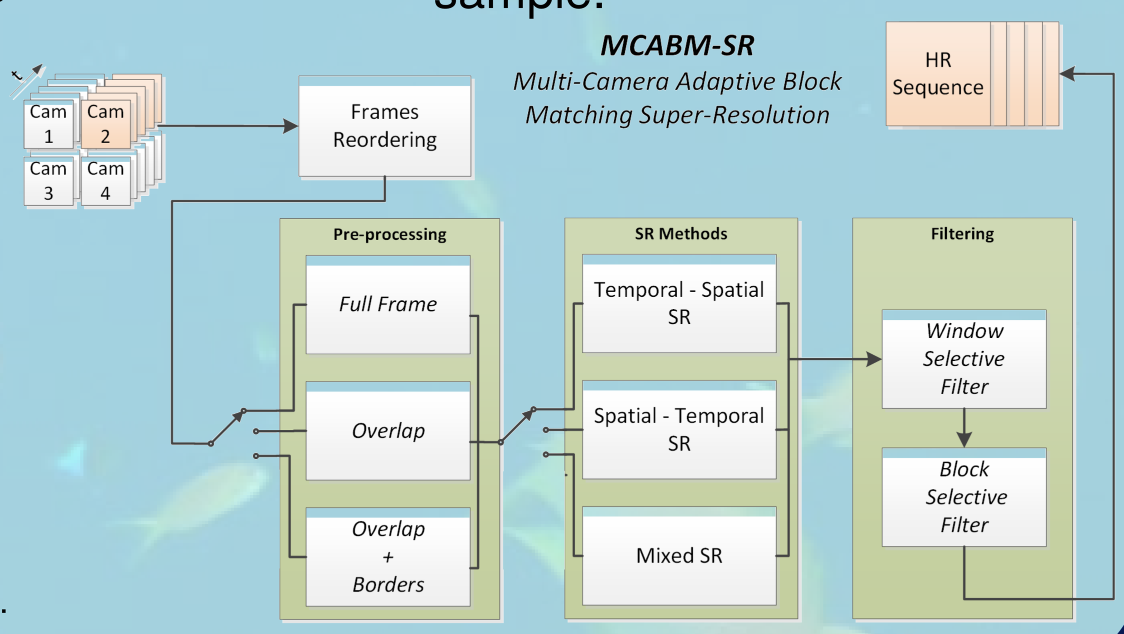


Fig.3: (Right) SR algorithm diagram.

EXAMPLE OF USE: Lucky Imaging

We have applied a selective filter for frames using the SSIM (Structural SIMilarity) objective metric developed for super-resolution underwater imaging to astronomical frames. By implementing SSIM selection algorithms into the Lucky Imaging (LI) procedure we have upgraded our method to obtain diffraction-limited astronomical images even under bad seeing conditions.

Lucky Imaging = Brightest pixel

Super resolution method = Similarity of each frame with respect to the reference using the Structural SIMiliraty Index (SSIM)

SOME RESULTS

Applying the SR method to some stellar sequences obtained with FastCam and AOLI we have not only reached the telescope diffraction limit but also increased the resolution of the final images.

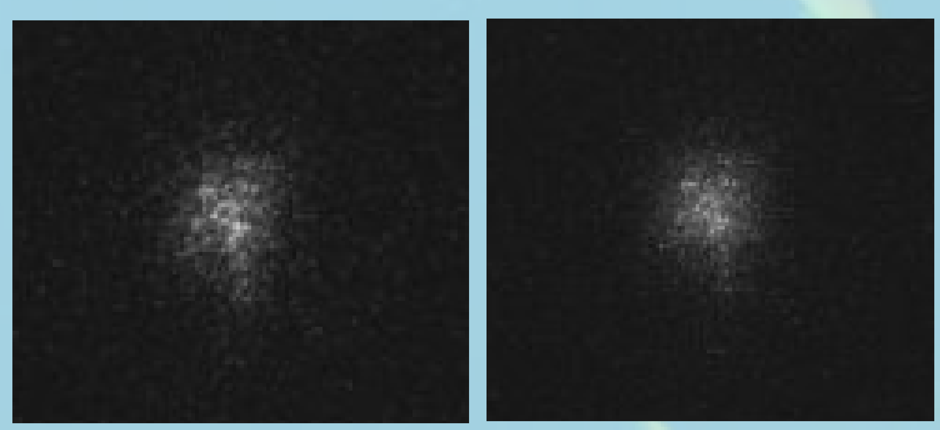


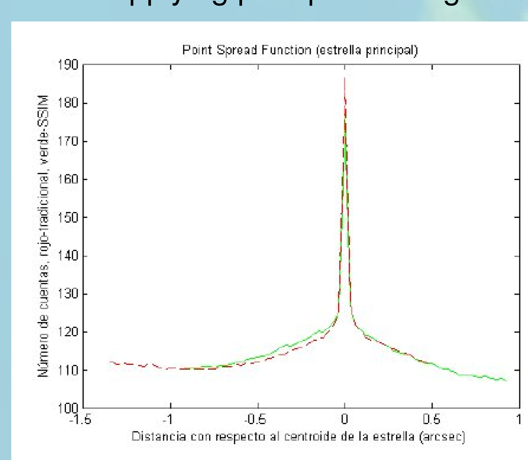
Fig. 4: Close binary frame. Raw image (left) and after the SR preprocessing (right), both frames before applying post-processing techniques.

An additional point in favour of the SR method is that it keeps the photometric information of the sources.

A comparison between the LI and SR methods is shown below. The advantages of using SR are evident.

Method	Brightest pixel (LI)					Structural Similarity (SSIM)				
%	NC_p	NC_s	dif	$FWHM_p$	$FWHM_s$	NC_p	NC_s	dif	$FWHM_p$	$FWHM_s$
1%	238	158	80	**0.002**	**0.371**	212	148	64	0.0035	0.4417
10%	201	130	71	0.0116	**0.5639**	188	130	58	**0.0082**	0.7322
30%	187	121	66	0.0169	0.879	177	123	54	**0.0141**	**0.7956**
50%	180	118	62	0.0189	1.1027	176	119	57	**0.0175**	**1.1026**
70%	176	116	60	0.0202	**1.2964**	175	115	60	**0.0199**	1.4313

Table 1: LI and SR methods comparison.



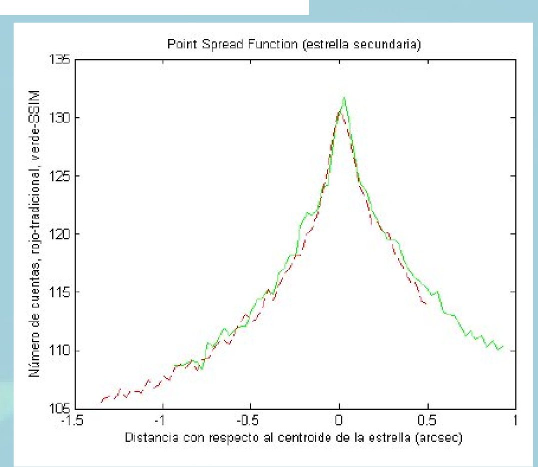
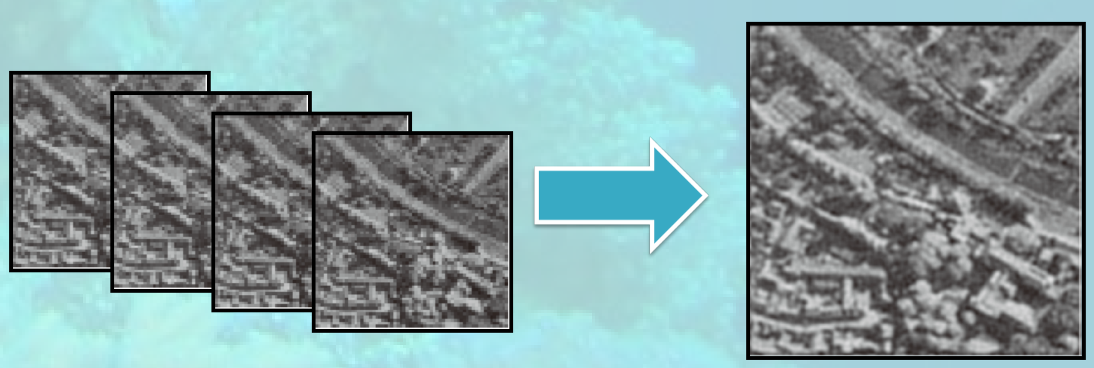


Fig. 5: PSF of the centering star (up) and a field star (right). LI appears in red, SR in green.

ASTRONOMY

The SR method developed for submarine applications have proved to be valid to improve the astronomical images, helping to avoid the atmospheric turbulence. The application presented here is based on the LI algorithm, but the SR methods can be applied to produce super resolution imaging in many astronomy fields:

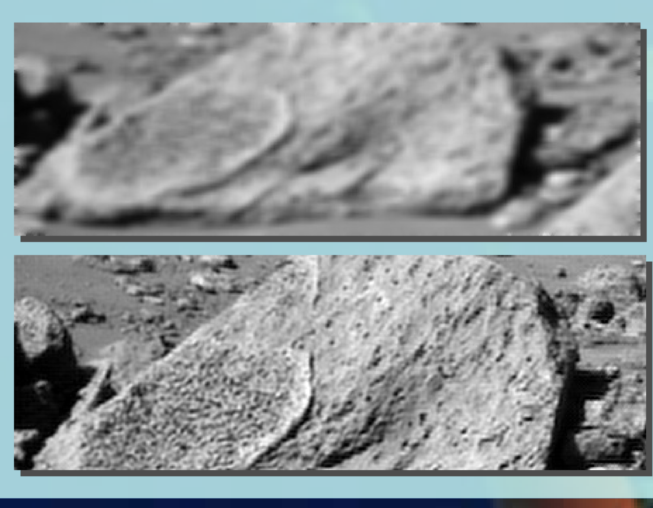


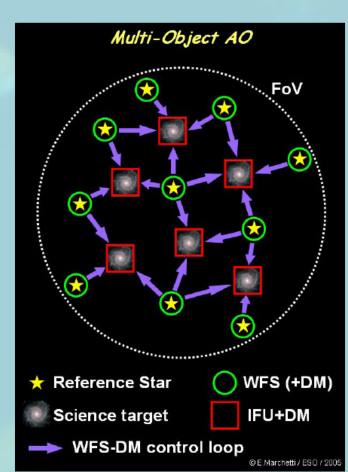
Multiconjugate Adaptive Optics (MCAO)

Satellite images

Multi-Camera systems

Multispectral imaging





Affiliations:

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References:

Quevedo et al. 2015

Velasco et al, 2016, MNRAS