CAMERA: A WEBCAM NETWORK TO IMPROVE THE REGIONAL COASTAL EARLY WARNING SYSTEM IN EMILIA-ROMAGNA (ITALY)

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A network of fixed webcam stations has recently been installed along the coast of the Emilia-Romagna region in Italy aiming to enhance the regional Coastal Early Warning System (EWS). The network integrates advanced video monitoring technology to collect and analyze data on coastal dynamics, offering a cost-effective solution to improve storm surge monitoring, shoreline mapping, and coastal management. By deploying eight strategically positioned cameras, the system provides high-resolution spatial and temporal data, enabling real-time monitoring and long-term analyses. This initiative supports civil protection efforts, informed decision-making, and sustainable coastal management while addressing challenges such as environmental monitoring during extreme weather events. The system architecture combines state-of-the-art imaging, processing capabilities, and a web-based visualization platform, adhering to open-source standards and accessibility guidelines. The project exemplifies an innovative, scalable approach to coastal risk assessment and environmental resilience.

Keywords: coastal webcam network, video monitoring, coastal management, coastal Early Warning System

INTRODUCTION

In the north-western Adriatic, the Hydro-Meteo-Climate Service of the Regional Agency for Protection, Environment and Energy of the Emilia-Romagna Region (Arpae-SIMC) manages a coastal Early Warning System (EWS) based on an operational chain of meteo-marine forecasting models. Outputs from hydrodynamics and wave models, forced with meteorological fields, are used as boundary conditions to a coastal morphodynamics model (XBeach) which provides hourly forecasts of storm impact indicators based on maximum water levels for three days. These indexes are then compared against predefined thresholds with this information being part of a Decision Supporting System (DSS) in the decision-making process by regional authorities (Harley et al. 2016).

However, the validation of such a system is difficult due to the lack of in situ measurements which would provide data to check the performance of the model. Collecting data that accurately reflects the state of coastal environments is crucial for effective coastal management and the establishment of EWSs but this task is both challenging and costly. One way of overcoming the aforementioned limitations is through video monitoring techniques, which allows researchers and operators to monitor and analyze the environment more accurately and in greater detail than would be possible with traditional monitoring methods (Van Koningsveld et al. 2007). Video monitoring has become a valuable tool for monitoring storm surges, assessing damage, and estimating post-event shoreline changes, helping to understand how beaches respond to extreme or long-term weather-marine phenomena.

As discussed in Davidson et al. (2006) and in Archetti et al. (2008), video monitoring has been widely used in various environmental applications, including coastal systems and transitional areas. Beaches constitute a dynamic environmental system where the effects of weather and marine phenomena, human activities, and the morphological and sedimentological characteristics of the coast lead to a constant evolution of the shoreline, sand volume, and seabed structure. Storm surges, due to their energy, cause rapid changes in the distribution of sand, with large amounts of sediment being re-circulated, often resulting in significant beach erosion.

Compared to traditional field monitoring, video monitoring offers several advantages, such as lower costs, reduced labor and maintenance requirements, and the ability to capture a wide range of high-resolution spatial and temporal data, even under adverse weather conditions (Myagmar-Ochir and Kim 2023).

Webcams used for coastal monitoring can be positioned at strategic locations (e.g. ports, beaches, rooftops of beach establishments, embankments, lighthouses, control towers, piers, or docks) and key parameters in the nearshore can be extracted from remotely sensed video (Holman and Stanley 2007; Davidson et al. 2006) and include shoreline position, surface currents (Chickadel et al. 2003) and wave run-up. Furthermore, by installing a video monitoring system, it is also possible to analyze the evolution of the shoreline with high frequency in time and during stormy conditions, aiming not only to

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increase knowledge of local processes, but also as a support system during such extreme weather events.

Based on these considerations, and inspired by previous existing systems and studies, such as ARGUS (Holman et al. 2007), CoastSnap (Harley et al. 2019), SIRENA (Nieto et al. 2010), La Victoria Beach, SW Spain (Montes et al. 2023), Picoastal (Stringari et al. 2022), VISTAE (Addona et al. 2022), the Hydro Meteo Climate Sevice of Arpae Emilia-Romagna, in coordination with the Emilia-Romagna Region and the University of Bologna, seized the opportunity provided by European funding through an Interreg Italy-Croatia program to develop the architecture for a regional webcam network (named camERa). This network aims to support the installation of several webcams for civil protection and territorial management purposes, as outlined above. The decision was made to start with the coast, installing eight stations, leaving the possibility of further installations in areas of particular environmental interest to be integrated into the existing network structure in the future.

The camERa network

The system involves the installations, setup, archiving, processing, and publication of data from eight fixed video monitoring stations along the Emilia-Romagna regional coastline (Figure 1). These stations, equipped with webcams capable of acquiring, processing, transmitting, and publishing images, form the coastal camera network. This network is designed to monitor beaches and shorelines. The primary objective is real-time monitoring of beach conditions, enabling the collection of long-term datasets to support decision-making processes in the management and planning of marine-coastal zones.

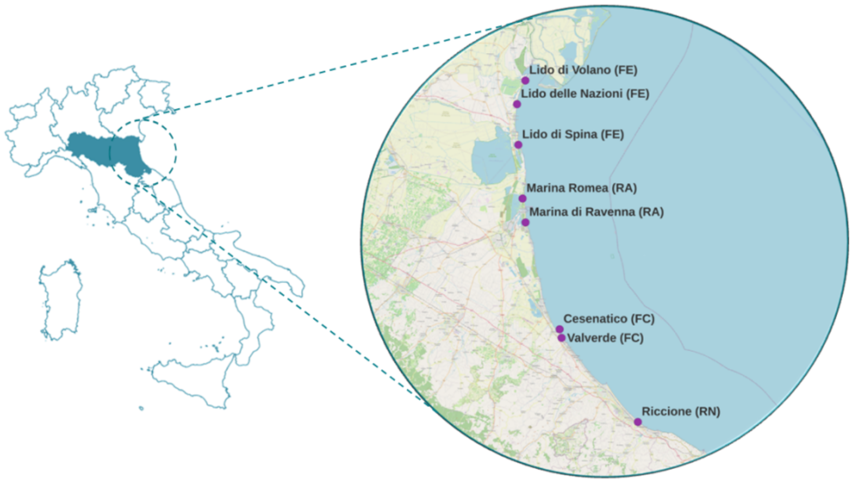

Figure 1. Webcam locations along the Emilia-Romagna coast

Each station is installed at a height of approximately 8 meters above ground level, providing an optimal view of the coastline for image processing and product generation. The stations capture video streams and images at regular intervals, including continuous periods of at least 20 minutes. They also support local archiving, processing, and the transmission of processed products and associated metadata to the Arpae Functional Centre archive. Remote access to individual stations is possible, allowing users to utilize local data, verify system functionality, adjust settings, and perform necessary software and firmware updates.

Each station comprises the following key components:

- Fixed industrial camera: designed for image and video acquisition, these cameras are readily available from major manufacturers and built to operate in challenging coastal environments (waterproof and resistant to mechanical impacts). They are equipped with variable zoom optics to adapt to different viewing angles, an Infrared (IR) illuminator for night vision, and a face masking function to ensure privacy protection. The cameras are selected to deliver the highest possible image quality, even in low-light conditions.
- Processing and control unit: this unit automatically acquires video streams or images from connected cameras at configurable intervals. It processes the data using specific algorithms (open-source software) to produce outputs such as TIMEX, TIMESTACK, SNAPSHOT,

shoreline, and orthorectified images. The processed data is stored in a local archive with a 30-day retention period.

- Power supply module: a 220 VAC power module equipped with an uninterruptible power supply (UPS) ensures continuous operation. Through its interface with the processing and control unit, the system can send notifications and alarms to the Web Application regarding the battery status of the UPS and any absence of power from the 220 VAC mains.
- 3G/4G/LTE communication module: This module, complete with an antenna, transmits processed products and metadata to the Arpae Functional Centre at configurable intervals (typically every 30 minutes).
- Ethernet communication provision: Stations also support Ethernet-based data transmission for additional connectivity options.

Given the characteristics of the Emilia-Romagna coast, two types of stations have been identified:

- Type A: host structures with a low height above ground level (3 m) and located in beach establishments, on average, close to the shore;
- Type B: host structures with a height above ground level > 8 m.

By analyzing the observation sites, the height of the camera mast has been evaluated with the aim of guaranteeing the acquisition of significant images at any time of the year (in fact, during the winter a containment dune is built, which must not affect the view of the coastline).

The camera characteristics:

- 5 Mpx resolution
- 2 Hz frame rate
- 200 m shoreline viewing distance
- Day and night operation (but daily images only are elaborated so far);
- Weather resistant marine housing
- PoE power supply
- Face masking function and sensitive data
- Illuminator for night vision
- Transmission interface via proprietary and open standard protocol (GigE Vision)

Two of the webcams installed can be seen in Figures 2 (Valverde) and 3 (Riccione).

Figure 2. Webcam installed in Valverde (FC).

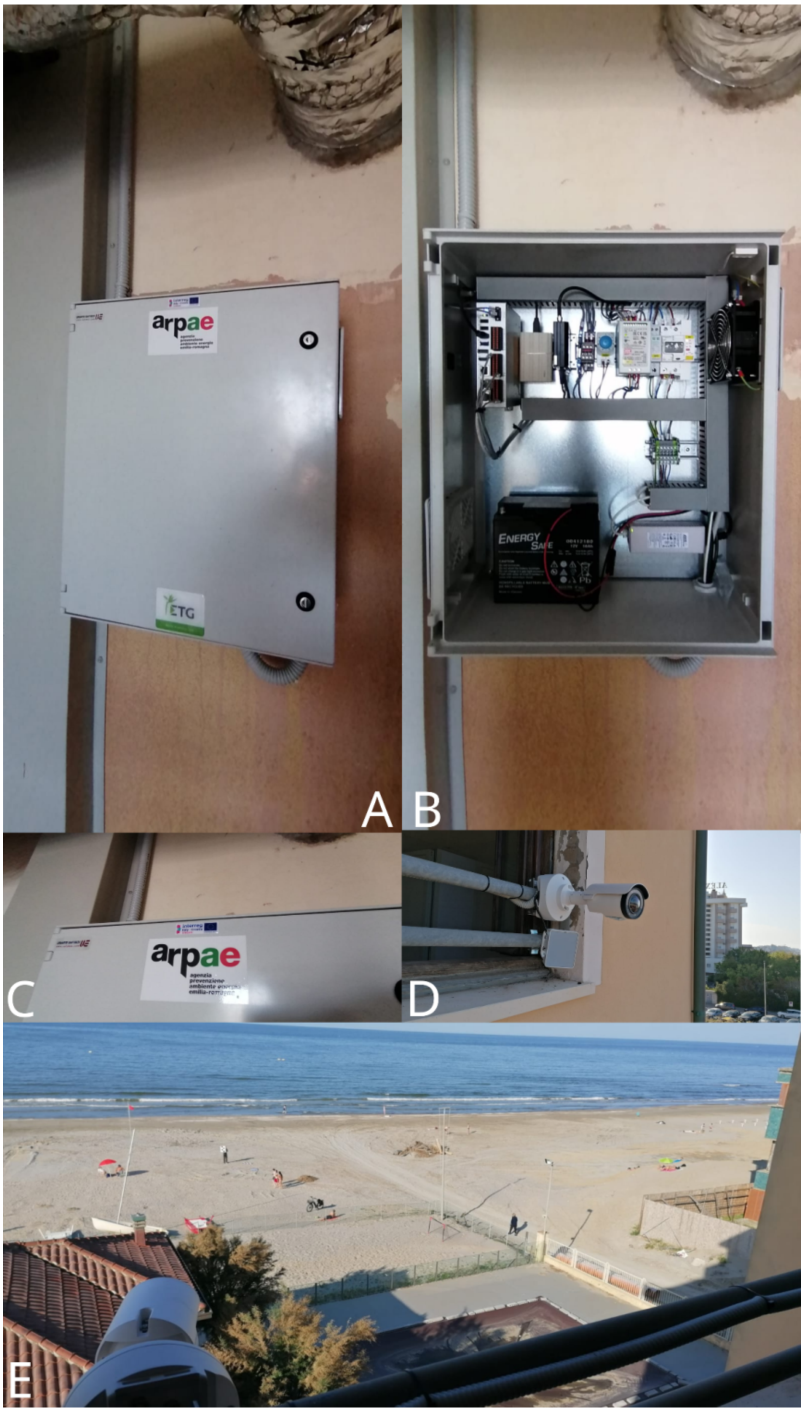

Figure 3. Webcam installed in Riccione. A, B, C) device installed which stores and initially processes the webcam data before sending to the other Arpae servers. D, E) Webcam installed and Webcam view towards the Adriatic Sea, respectively.

System architecture

Given the availability of a virtual environment within Arpae's infrastructure, this platform serves as the natural location for the web-based visualization of products generated by the video surveillance network. To minimize network traffic, only processed products are transmitted to the central infrastructure, while raw images and videos acquired by the cameras are stored locally.

As shown in Figure 4, remote stations process camera data (1), generate products, and send them to the FTPS server provided by Arpae that publishes the data on the dedicated project portal, called Coastal Portal (described later). This data is transferred to both Arpae's database (referred to as Arkimet, comprising a set of open-source tools for the organisation, archiving and distribution of data files, see https://github.com/ARPA-SIMC/arkimet) and a local storage.

The web platform (2) provides two access areas: an area with anonymous access for consultation only and an area requiring authentication via credentials (AUTH module), which allows users to modify configurations and request raw data as if directly connected to the remote site's web server.

A local software interface (3) allows to configure settings and access raw data.

The system includes a caching module (CACHE) that evaluates data requests and either fulfills them from the central database or forwards them to the remote station.

Communication between the server and remote stations is via HTTPS, with firewall rules allowing access only to Arpae's server.

Data is consistently stored in the Arkimet database, centralized Local Storage, and remote stations, ensuring maximum resilience and redundancy.

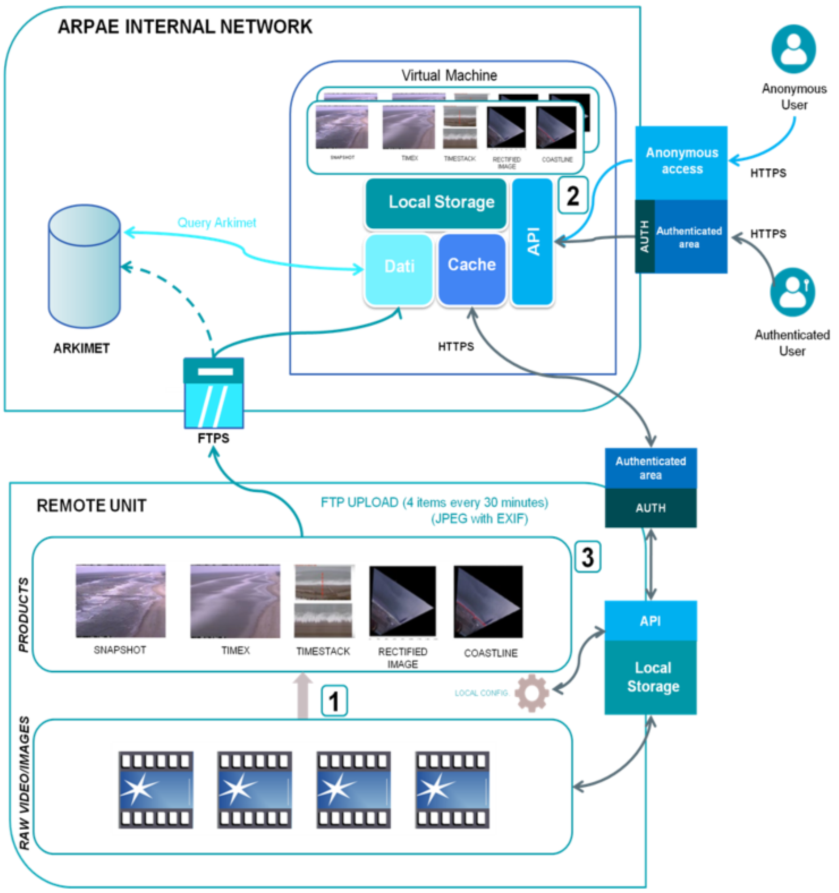

Figure 4. System architecture

Image acquisition, processing and transmission unit

The camERa system employs an embedded industrial PC featuring a high-performance CPU, 8 GB of RAM, and a high-speed SSD for storage. The system operates on the Ubuntu 22.04 LTS Linux operating system, a choice that ensures stability and reliability, while delivering superior performance for the given hardware resources. The adoption of a Linux-based platform offers users a high degree of customizability, enabling fine-tuning and optimization of system performance to meet specific project needs. This combination of hardware and software is designed to achieve a balance between robust system reliability and the computational demands of high-resolution video processing.

The system is configured to capture raw images, referred to as SNAPSHOT (Figure 5A), at a frequency of 2 Hz to balance image capture frequency, CPU load and operating temperature. The collected images are processed in-situ, in configurable time steps, to reduce the load on the server and to perform the following tasks:

a) image undistortion: aims at removing the effects of lens curvature and projection on the image plane, while the image rectification task consists in projecting the the whole or a part of the captured image from the image reference system onto a horizontal plane specified by the user;
b) image rectification (RECTM): consists in projecting all or part of the captured image from the image reference system onto a horizontal plane specified by the user, with real world coordinates, allowing its use in GIS environments (Figure 5C);
c) TIMESTACK collection: highlights the evolution of the surf zone during the sampling period, allowing the visualisation and estimation of the temporal evolution of the beach (Figure 5D);
d) time averaging (TIMEX): a representative image of the sea conditions near the shore, obtained by averaging raw images (SNAPSHOTS) over a 30-minute interval (Figure 5B);
e) time variance calculation;
f) shoreline extraction (TMXSH): shows the shoreline position on the TIMEX image (Figure 5F)
g) shoreline extraction (RECSH): shows the shoreline position on RECTM image (Figure 5E).

All the software developed is open source: the underlying engine is provided by OpenCV (Open Computer Vision Library, https://opencv.org), while the Python computational layer is based on Numpy (https://numpy.org) to speed up the computations. As the images are definitely multidimensional arrays, several tasks have been parallelized to reduce the computation time and also to balance the available hardware.

Shorelin extraction is performed on the TIMEX image using the iterative implementation of the GrabCut algorithm coded in the OpenCV library for foreground extraction (Rother et. al. 2004) based on the Graph-Cut theory, for further details see the OpenCV documentation (https://docs.opencv.org).

Each of the camERa sites has been calibrated for intrinsic and extrinsic parameters used in the previously listed tasks. For this purpose, the tools provided by OpenCV (https://docs.opencv.org/) and specific routines developed in the TAO projects (funded by Emilia-Romagna ERDF ROP 2014-2020) have been used on data collected in situ (ground points, camera position and chessboard images) as described in Addona et.al. (2022).

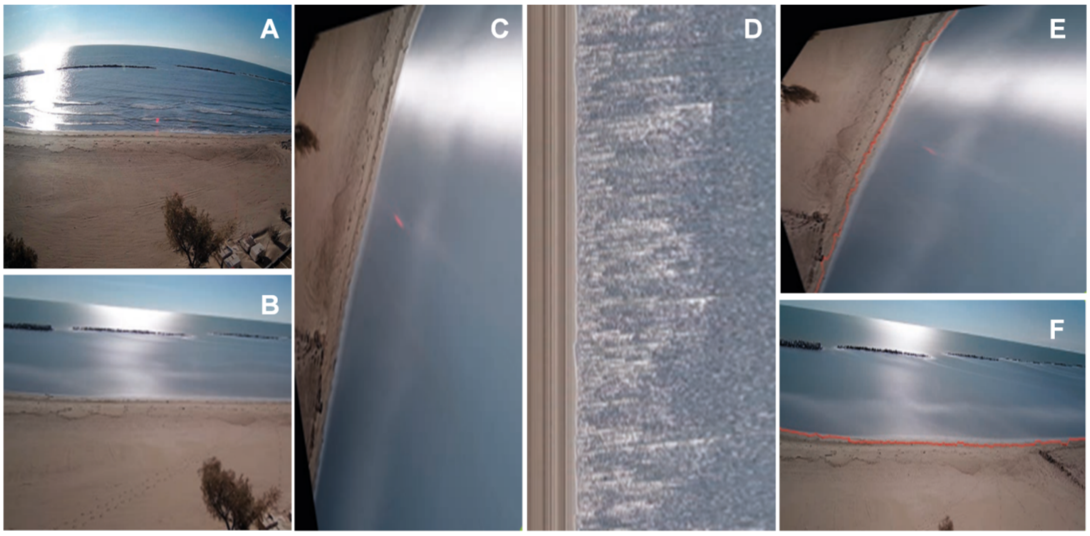

Figure 5. Example of SNAPSHOT (A), TIMEX (B), RECTM (C), TIMESTACKS (D), RECSH (E) and TMXSH (F) for the Riccione site.

Web visualization - Coastal Portal

To present processed data in a simple and effective manner, enabling accredited users to retrieve raw data or modify device configurations, a web-based software environment has been developed. This platform adheres to Italian guidelines, ensuring compliance with national accessibility regulations (docs.italia.it/italia/design/lg-design-servizi-web/it/versione-corrente/index.html).

Each remote monitoring station hosts a LITE version of the portal, allowing configuration and data analysis through secure authentication. The FULL version, hosted on the main server, provides centralised configuration access for all stations, visualisation of data processing results and a GIS module. The GIS interface is publicly accessible without authentication, allowing users to view all stations and their latest data.

The GIS module is developed using geospatial libraries to effectively represent monitoring locations. It uses open source Leaflet.js libraries to ensure interoperability with third party information systems while maintaining the simplicity, usability and accessibility of the platform.

Users can interact with the GIS module by selecting an icon representing a specific video monitoring station. This action displays summary information, including station metadata, the date and time of the last update, and a visualisation of the most recent data received. Guest users are limited to viewing only a recent history of SNAPSHOT, TIMEX, RECTM and TISTK images.

The GIS module also includes camera status monitoring functionality. If a camera fails to transmit data for at least 10 hours, the icon representing the station changes its appearance, including the colour of the marker, to indicate a problem with the station's connectivity.

camERa network is accessible at the address https://simc.arpae.it/stream_camera/gis/map

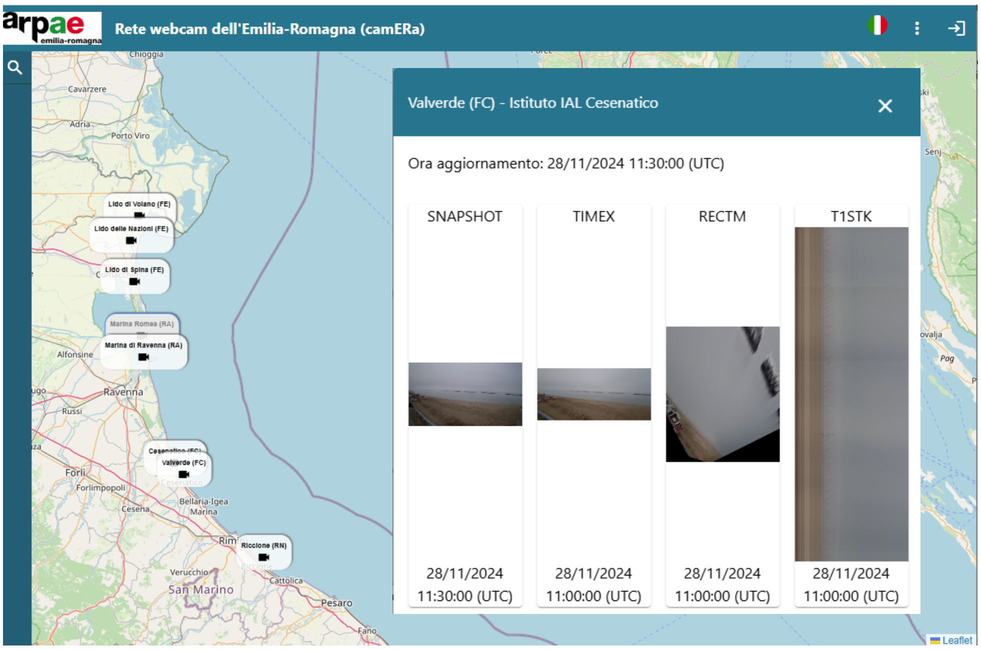

Figure 6 – Web platform visualization and the specific products visualization for the Valverde (FC) webcam (as example).

DATA ELABORATION AND PRODUCTS

The operational camera database provides a rich source of information from which a variety of detailed analyses can be carried out. These include an assessment of the impact of storm surges on coastal areas, estimation of wave run-up, detection of bathymetry through analysis of wave propagation fronts, and measurement of intertidal beach bathymetry. There are numerous examples in scientific literature that could benefit from the configuration of a network of cameras, including those presented by Romagnoli et al. (2021).

To illustrate one of the many capabilities of the system, we present the detection of isobaths in the intertidal zone, an area that presents challenges for direct measurements. The matching between tidal measurements and the shoreline, obtained simultaneously, enables the reconstruction of intertidal bathymetry under calm sea conditions.

Figure 7 depicts the RECSH images captured by the Lido di Volano camera between 2:30 and 7:00 p.m. on June 5, 2024. On each image the coastline is detected and represented by a coloured contour line.

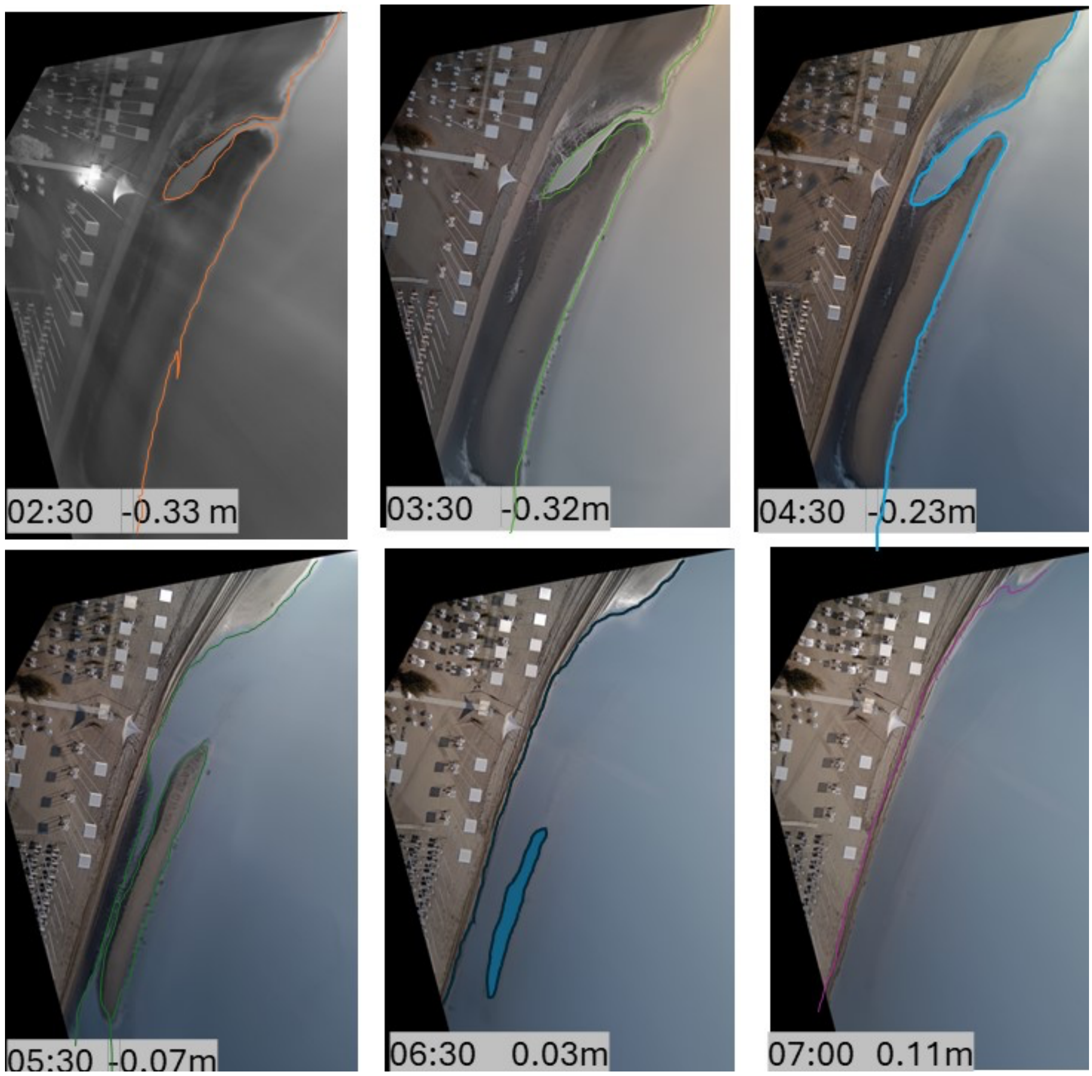

Figure 7. RECSH at Lido di Volano. June 5, 2024. The coloured contour line indicate the shoreline position. On each plot the time and the corresponding sea level at tide gauge is indicated.

Due to the tidal excursion the Sea Water Level (SWL) at each detection time varied between -0.35 m to +0.20 m the SWL was simultaneously measured by the tidal gauge located in Porto Corsini (Figure 8 right) where the colour of the square corresponds to the isodepth. The isodepth collected in the range between -0.35 m to +0.20 m are drawn in Figure 8 (left).

An interpolation of the isodepths allows the creation of a DTM of the intertidal beach bathymetry.

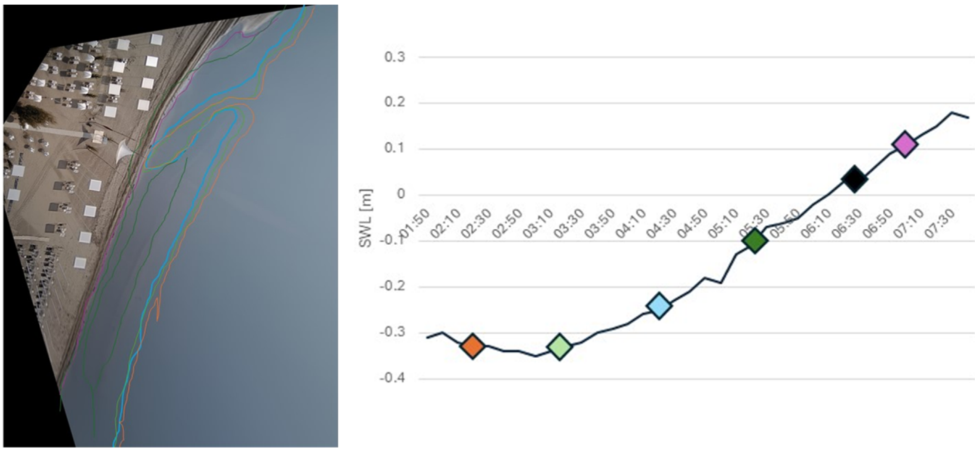

Figure 8. SWL measured on June 5 2024 by tidal gauge located in Porto Corsini (right). The colour of the square corresponds to the isodepth (left).

The comparison of intertidal beach bathymetries allows a detailed estimation of the morphodynamic in this area, so important for the understanding of the complex dynamics of the swash zone. Examples of applications are given in Archetti (2009), Aarninkhof et al. (2003), Vousdoukas et al. (2011).

CONCLUSIONS

The implementation of the camERa network demonstrates the potential of video monitoring systems as an integral component of modern coastal management and risk adaptation strategies. By leveraging advanced imaging technologies, real-time data processing, and web-based platforms, the system enhances the operational capabilities of the regional Coastal EWS in Emilia-Romagna. The system not only provides a scalable model for integrating video surveillance into coastal monitoring but also addresses the limitations of traditional data collection methods, offering high-resolution insights into shoreline dynamics and storm impacts. As coastal regions face increasing pressures from climate change and extreme weather events, the camERa initiative underscores the importance of innovation, collaboration, and data-driven decision-making in achieving sustainable environmental stewardship and disaster preparedness.

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