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Integrating images and thermal signals with advanced algorithms

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Abstract: This work considers possible approaches to improving the quality of image signal formation in both light and dark periods of the day, as well as reducing the impact of noise, interference, and artifacts on image signal characteristics. It is proposed to use the wavelet domain for the analysis of thermal and image signals with their subsequent possible complexation. The main features of the formation of such signals are indicated. It is shown that the proposed approach allows to improve the quality characteristics of image signals, especially in the dark period, as well as to ensure their effective processing related to filtering, compression, scaling and contrast change. A comparison of the obtained results of the proposed method with other existing similar signal processing approaches is given.

Keywords: Thermal signals; video signals; complexation of signals; wavelet transformation

1. Introduction

Throughout the history of the use of video cameras, the main problem in them has been to ensure high quality and contrast of images, especially in poorly lit places and in the dark. To improve such images, various methods and approaches related to selection and enhancement of poorly visible parts of images were used. Recently, thermal signals are additionally used for such cases, based on which image signals are formed. However, if you use only this type of signals, it is difficult to achieve high-quality images with them during the daylight hours. In many cases two cameras are used, i.e. video and thermal. Combining video and thermal signals in this way improves the effectiveness of video surveillance systems in conditions of limited visibility, such as fog, smoke or nighttime. Video may not be productive in such situations, as objects may be difficult to see. Thermal signals, which reflect the thermal radiation of objects, are independent of visibility and can provide useful information about the movement of objects, even in poor visibility conditions. The combination of video and thermal signals allows to increase the sensitivity of the moving object detection system and ensure reliable detection even in difficult conditions. In the latest technical developments, efforts are being made to combine the work of video and thermal cameras. The main difficulty of such cameras is that the processing of different wavelength signals in such devices is carried out in different areas and the implementation of their combination is significantly complicated. In view of this, the work proposes the use of the energy domain for presenting both signals (wavelet domain) and their complexation in this domain, which allows to obtain better quality improvement of image signals at different times of the day.

2. Object and subject of research

The object of research is the integration and combination of video and thermal signals, aimed at enhancing the quality and reliability of the combined imagery for various applications, particularly in object detection and recognition.

The properties and parameters defined in this article:

- Video Signals: Standard video signals captured by regular cameras, which provide visual information in the visible spectrum. These signals are characterized by parameters such as resolution, frame rate, color depth, and dynamic range.
- Thermal Signals: Infrared signals captured by thermal cameras, which provide information about the heat emitted by objects. Key parameters include thermal sensitivity, temperature range, resolution, and refresh rate.

The advances in machine learning and computer vision have led to innovative methods for combining video and thermal signals. For instance, convolutional neural networks (CNNs) are employed to enhance the fusion process, improving accuracy in object detection and reducing false positives. And this leads to the primary idea: to leverage the complementary information provided by video and thermal signals to create a more informative and reliable image. While video signals offer detailed visual context, thermal signals provide critical information about the heat signatures of objects, which is especially useful in low visibility conditions.

The system operates by first capturing video and thermal images of the same scene. These images are then aligned (co-registered) using algorithms that account for differences in perspective and resolution. Once aligned, the images are combined using wavelet transformation, and deep learning-based approaches. The resulting image integrates visual and thermal information, enhancing the overall scene understanding.

Characteristic Shortcomings:

- The fusion methods can be complex to implement, often requiring advanced algorithms and significant computational resources.
- High-quality fusion may necessitate specialized and expensive equipment, including high-resolution thermal cameras and powerful processors.
- Ensuring that video and thermal signals are perfectly synchronized and co-registered can be challenging, particularly in dynamic scenes with moving objects.
- Real-time processing of combined signals can be demanding, potentially leading to latency issues in applications where immediate feedback is critical.
- The performance of thermal cameras can be affected by environmental factors such as weather conditions and ambient temperature, which may introduce noise and reduce the accuracy of the combined images.

3. Target of research

The research focuses on analyzing the main methods of combining video and thermal signals in a wavelet domain to determine possible directions for improving quality characteristics. The goal is to evaluate the effectiveness of these methods based on metrics such as accuracy, sensitivity, specificity, and speed.

4. Literature analysis

Observations in low-light conditions and in total darkness are one of the most important areas of research conducted in the field of electronic instrumentation. It is known that the need for such highly efficient devices especially arises in military affairs, as well as in various new branches of the national economy [10,13]. Modern achievements in this area, especially in recent decades, have contributed to the emergence of new surveillance devices with many information channels, at least television and thermal imaging. To combine the information of such channels, the signal complexing operation is used [9,12]. In recent years, research in the field of complexation has shown a high qualitative and quantitative advantage in solving the problems of detection, recognition, tracking and targeting of relevant objects [11]. The complexing process increases the informativeness of the resulting image compared to the images obtained in individual channels of the system, which significantly improves the operator's awareness of the situation and increases the efficiency of the system. The television channel forms spatial contrasts of objects due to the reflection of solar energy in the visible frequency range, which leads to changes in signal levels depending on the state of external lighting. On the other hand, the thermal imaging channel has a low-variable signal, because it perceives the radiation of objects relative to the background, which changes rather slowly. In addition, day and night observation conditions in the channels can also differ significantly. As the relevant studies show, for the analysis and complexation of signals, the presentation of both information signals in the wavelet domain with their subsequent possible complexation is best suited [8].

5. Research methods

It is known that a video signal is an electrical signal that transmits visual information about objects using visible light. Modern video cameras form video signals in the range of wavelengths from 380 to 700 nanometers, but they do not necessarily capture all colors of the spectrum. Depending on the types of sensors, video cameras can have different sensitivity to different wavelengths of light. For example, cameras with CMOS sensors work in the range from 1100 nm (infrared light) to 200 nm (near ultraviolet), and *CCD cameras* work with wavelengths of 400 - 1050 nm, which is especially important in light detection (photometry), as well as for medical and professional purposes where high-resolution images are required.

Instead, thermal signals exist in the infrared range, i.e. with wavelengths from 700 nm to 1 mm. Thermal cameras or thermal imagers are used to detect these signals. In such cameras, the sensors are matrixes with thousands of detectors sensitive to IR rays, which convert a thermal signal into an electrical one. Modern thermal imagers typically operate in two main bands: short-wavelength (SWIR) and medium-wavelength (MWIR). The SWIR range has a wavelength of 1.4 to 3 μm, and the MWIR range has a wavelength of 3 to 8 μm.

It is also known that the human eye perceives an image in the form of light reflected by various objects. No light means no reflection. Thermal imaging, on the other hand, is independent of visible light. Instead, they are formed by operating in the thermal IR spectrum and work even in complete darkness, as the level of ambient light is irrelevant.

Advantages of combining video and thermal signals

The integration of video and thermal signals involves the summation of information obtained from video and thermal signals to obtain a completer and more useful picture of the observed objects. Such a process includes simultaneous display and analysis of video and thermal images, as well as combining them into one integrated image.

The combination of video and thermal signals is useful in several cases, depending on the combination of these systems it is possible to obtain certain features that could have been unnoticed before, increase the accuracy of the display, and improve the perception of human vision. The significant advantages of the combination of video and thermal signals include:

- obtaining additional information; integration of video and thermal signals [2] allows you to get a more complete picture of the situation or object; thermal images provide additional information about thermal distribution, temperature differences, and areas of increased thermal activity that are not visible on conventional video recordings. and allow you to detect hidden problems, anomalies or hazards.
- improvement of detection (selection); complex analysis of video and thermal signals provides more accurate detection of objects or events [3].
- increasing the effectiveness of analytics; combining video and thermal signals allows applying intelligent data analytics to obtain useful information [6].
- expansion of opportunities in the field of security; the combination of video and thermal signals is an effective tool in the field of security; video recording provides visual identification, and thermal imaging complements it.

Thus, the indicated advantages show the importance of combining video and thermal signals for obtaining more complete and accurate information, improving safety and efficiency of processes in various industries [2].

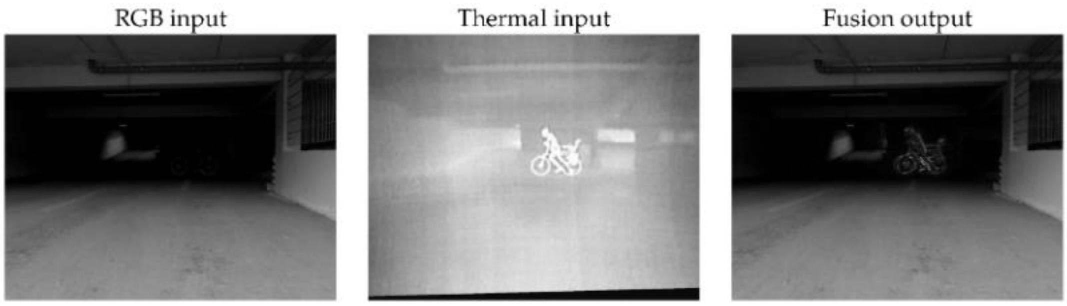

Figure 1. Combination of thermal imaging and video information.

Modern methods of combining video and thermal signals allow obtaining additional useful information from various sources. The choice of the complexation method is mainly determined by the task and the formulated requirements for the final images. Today, several methods of combining video and thermal signals are known, which primarily include methods of joint registration, image synthesis, data merging, and data processing and analysis.

Method of joint registration. This method is one of the key methods of combining video and thermal signals. It is used to align video and thermal images by detecting and accounting for geometric transformations such as displacement, scaling, and rotation [2], ensuring an accurate match between objects and details in images from different sources. In fig. 2 shows the process of joint registration and normalization on the example of the human brain. According to the algorithm, features are initially detected on video and thermal images. Features can be points, corners, or descriptors that can be localized and described. After identifying features, correspondences between features on video and thermal images are established.

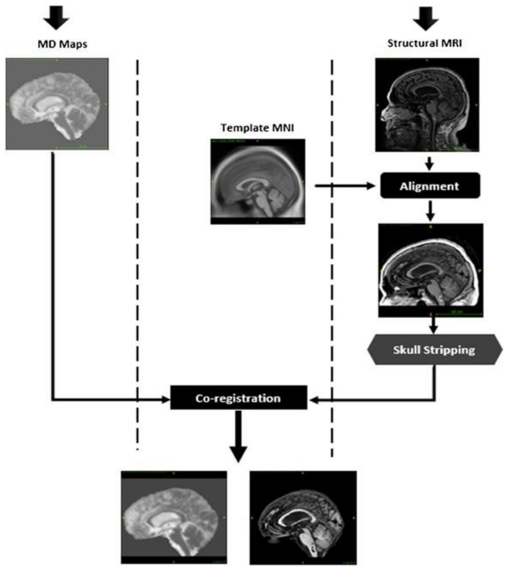

Figure 2. The structure of the process of joint registration and normalization on the example of the human brain.

The next step involves the transformation between video and thermal images. At the same time, shifting, scaling, rotation or a combination of the mentioned operations can occur.

An important step is to evaluate the quality of the co-registration, which is provided by evaluating metrics such as the sum of squared differences or the correlation between the aligned images.

The co-registration method can include various approaches and techniques, including:

- pattern search, which consists in finding relevant areas in video and thermal images by comparing patterns,
- optical flow determination, which determines the speed of movement of objects in the video, by analyzing changes in pixel values between successive frames,
- conducting correlation filtering, which is based on the use of correlation filters to find the maximum similarity between video and thermal images [4],
- determination of special features or descriptors, which are used to evaluate the correspondence between video and thermal images [4],
- the determination of geometric correspondences, which involves the use of geometric principles to determine the correspondence between video and thermal images.

It should be noted that the method of joint registration of video and thermal signals has a few significant advantages, which primarily include high accuracy of alignment of objects and details on video and thermal images, the possibility of saving information, as well as predicting movement, detecting anomalies, determining thermal profile.

The disadvantages of this method include, first, the possibility of the influence of noise on the input images on the correct alignment of objects, high computational complexity, especially when working with large volumes of data, the establishment of certain requirements for lighting conditions, the possibility of the influence of intense movement of objects can lead to artifacts or blurring.

Image synthesis method. This method is aimed at combining video and thermal images into one complex image. According to this method, thermal information is superimposed on the video, creating a mosaic image or using image synthesis algorithms to combine information from both sources [3].

Image synthesis corresponds to the process of combining information from different sources or modalities to create a new image that has more complete, contextual information. In the context of combining video and thermal signals, image synthesis is used to combine video and thermal images to obtain a completer and more informative image that can help in object recognition, pattern detection and situation analysis [4].

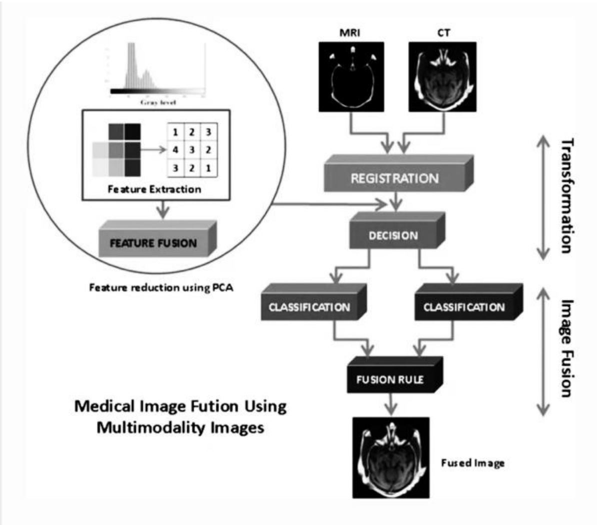

Figure 3. Structure according to the image synthesis method.

This method is based on the use of the principles of fuzzy set theory, which allows converting numerical data into fuzzy sets, modeling and processing fuzzy information [2]. Using methods of logical rules or fuzzy logic algorithms to combine information from different sources [2]. This method of combining video and thermal signals is also characterized by flexibility and ease of integration and can be easily implemented in a variety of devices, including mobile phones, tablets, computers and specialized systems.

Currently, there are several approaches to image synthesis, namely:

- weight compatible synthesis: the use of appropriate weighting coefficients is assumed for each image depending on their importance or quality; the images are combined by weighted addition, where the weights reflect the degree of influence of each image on the result.
- formation of a model based on intersection; an intersection operation is used to combine images; the pixel of the final image is calculated by selecting the minimum value from the pixels of the input images.
- formation of a model based on association; a merge operation is used to merge images; the pixel of the final image is calculated by selecting the maximum value from the pixels of the input images.
- carrying out multiscale analysis; image analysis is performed at different scales to highlight various details and structures; the images are split into different scales and then combined, considering the information from each scale.

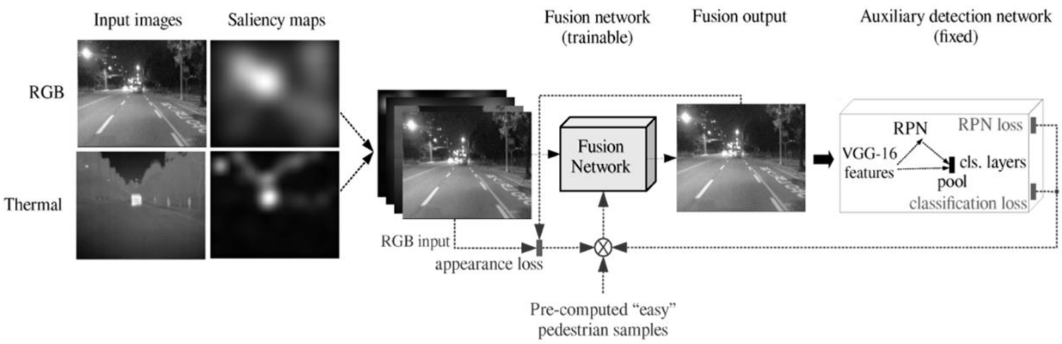

Figure 4. The process of converting two images into one using the synthesis method.

The image synthesis method has several advantages, which include:

- improved image quality: image synthesis produces higher-contrast, clearer, more detailed, and more contextually rich images by combining information from different sources.

- increased recognition of objects; the integration of video and thermal signals allows obtaining more complete information about objects, their thermal footprint and visual appearance, which improves their recognition and detection.
- improved operation in conditions of limited visibility; in a combination of video and thermal signals, you can get an image that displays the thermal information of objects even with limited visibility or poor lighting conditions.

At the same time, there are some challenges when using image synthesis, in particular:

- solving the problem of image alignment; combining video and thermal images requires accurate alignment of two images from different sources and correct combination of their information.
- choosing the optimal method; since there are many methods of image synthesis today, the choice of the most effective one depends on the specific application, the available data, and the requirements for accuracy and efficiency.

Considering the existing advantages and challenges, the image synthesis method is a powerful tool in the integration of video and thermal signals, which allows obtaining more complete, informative and contextually richer information for various application areas, including monitoring, security, navigation and object recognition.

The method of combining data. This method is used to combine video and thermal data at the data level, not just at the image level. This includes synchronizing, aggregating and processing data from both sources to produce more complete and comprehensive information. Combining data is an important stage in the integration of video and thermal signals. This process involves gathering, processing and combining information from different sources to get a completer and more informative picture.

The main goal of data fusion is to combine video and thermal information in such a way as to obtain a balanced data set that maximizes information value and helps to understand the situation. Most methods of combining data include:

- time synchronization: video and thermal data must be synchronized in time to correctly display events and phenomena, which requires the use of synchronization devices.
- data calibration: thermal data may require calibration to reflect actual object temperatures.
- data formatting and processing; video and thermal data can have different formats and resolutions, so combining and merging them requires data conversion and processing.
- combining information; video and thermal data can be combined in various ways, by merging images, statistically, using conflict resolution algorithms, which additionally allows combining visual and thermal information.
- visualization and analysis; combined data can be visualized and analyzed using special software or tools.

The method of combining data when combining video and thermal signals has its advantages and disadvantages, which should be considered when using it. Thus, increasing the volume of information when combining video and thermal data allows you to obtain more complete and contextually richer information about objects and events, and the complexation of signals allows you to reduce the impact of noise and the appearance of blackouts that may occur in one of the sources, in addition to this achieve high resolution when detecting small details of objects. [1]

Of course, there are some disadvantages when combining these signals, in particular:

- processing complexity: combining video and thermal signals requires the use of complex algorithms for data processing and analysis, which requires significant computing resources and expert knowledge for effective implementation.
- high cost: the use of equipment and software for video and thermal signal integration is quite expensive.
- dependence on external conditions; some methods of combining data may be sensitive to changes in lighting conditions, temperature and other external factors, which may affect the quality and reliability of the obtained data.

Despite the mentioned shortcomings, the data fusion method is an effective tool for obtaining more complete and valuable information using video and thermal signals. Considering the advantages and disadvantages, it is important to choose the approaches and methods that best suit the specific needs of the consumer.

Data processing and analysis method. This method is used to extract useful information from video and thermal data by applying various algorithms and techniques, such as object detection, tracking, classification, temperature measurement, etc. [2].

The method of data processing and analysis occupies one of the central places in the integration of video and thermal signals. This method includes a wide range of techniques and approaches for processing and analyzing the received data to obtain valuable information and understand various aspects of the observed scene.

First, there is a stage of filtering, normalization, noise reduction and other techniques to improve the quality and homogeneity of the data. It is aimed at removing noise, equalizing lighting, compensating for overlapping objects, and performing other corrective actions to improve data quality.

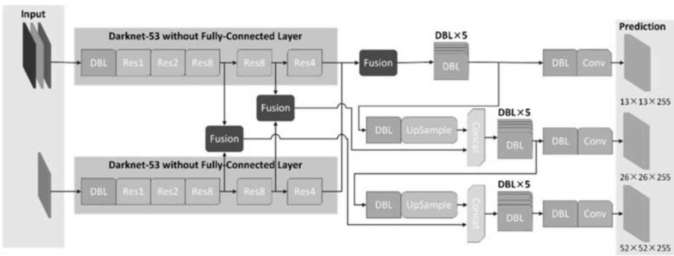

Figure 5. The structure of operations according to the method of data processing and analysis.

In the future, the process of extracting useful features from the processed data takes place. These may include statistical characteristics, textural characteristics, geometric characteristics, temporal characteristics, and other aspects that reflect important aspects of the studied objects and scenes.

At the next stage of data analysis based on processed features, various methods and algorithms are used to detect, classify, recognize and interpret objects and scenes. At the same time, machine learning methods, statistical analysis, neural network models, artificial intelligence algorithms, and other approaches can be used to obtain summary information and determine features [7]. At the final stage, visualization and interpretation of the obtained results takes place, which may include visualization of objects in the images, creation of maps or graphs, analysis of statistical dependencies and identification of important patterns. Visualization allows you to better understand and interpret the results of data processing and analysis.

Thus, the method of data processing and analysis includes a number of principles that are used to effectively use data and obtain valuable information, namely: the balance of accuracy and data processing, including a large volume, machine learning and statistics for recognizing and identifying important features, using visualization, which allows you to present complex data in the form of convenient forms for establishing dependencies in them, data quality control, which allows you to detect and correct errors, filter noise and compensate for missing data, evaluate the effectiveness of data processing in terms of computational complexity and time of operations , taking into account the context of the tasks and the specifics of the data, which must be adapted to specific tasks and take into account the peculiarities of video and thermal signals [4].

The advantages of the data processing and analysis method include:

- high efficiency of fast processing of large volumes of data processing; the use of optimized algorithms and machine learning methods allows you to quickly identify patterns and obtain valuable information from data.
- high accuracy of the obtained results, as this method allows for detailed data analysis and revealing complex dependencies and providing accurate forecasts.

- assessing the context of the data and the surrounding situation, which helps to discover complex relationships and establish relationships between different elements of the data.
- the possibility of automation and reduction of the human factor.

The main difficulties in implementing the data processing and analysis method are:

- dependence of the method on the quality of input data; implementation requires high-quality input to achieve accurate and reliable results.
- the complexity of choosing an effective method of data processing and analysis, which requires a deep understanding of the problem and features of the data.
- limited interpretability of the obtained results; when applying complex machine learning algorithms, results may occur without a clear theoretical explanation.

The given method of data processing and analysis is one of the important methods of combining video and thermal signals. It allows you to obtain important information from the data, to recognize objects, to solve the task of classification and understanding of the surrounding situation. However, ensuring effective data processing and analysis can face challenges related to the complexity of processing large volumes of data, ensuring the accuracy and efficiency of algorithms, and using approaches to understand complex scenes and objects.

6. Research results

The main feature and complexity of combining video and thermal signals is that these signals are in different frequency ranges (420-800µm for video and 2-12µm for thermal imaging signals) and have different intensity levels. In view of this, it is convenient to represent both signals in the same wavelet region, where they have the same energy representation. As a result of such representation, two sets of wavelet coefficients of both signals are obtained in the time-frequency domain.

If the dependences of video signal $f_1(x)$, thermal $f_2(x)$, basic function $g(x)$ are functions of finite energy (in $L^2(R)$ space), and $g(x)$ is an admissible function, then the wavelet transform of both signals can be represented as follows.

$$\left(W_\psi f_1\right) = |a|^{-\frac{1}{2}} \int_{-\infty}^{\infty} f_1(x) g(x)\, dx,\ \ f_1 \in L^2(R) \tag{6.1}$$

$$\left(W_\psi f_2\right) = |a|^{-\frac{1}{2}} \int_{-\infty}^{\infty} f_2(x) g(x)\, dx,\ \ f_2 \in L^2(R) \tag{6.2}$$

An important feature of this representation is that the same basic function is used for the wavelet transformation of both signals.

In the case of direct discrete wavelet transformation (DWTP), “wavelet coefficients” $c'_{j,k}$ (j = 1,...J)and scale coefficients $b'_{J,k}$of image signals are calculated:

$$\mathrm{DWT}\left\{x'[n]; 2^j, k2^j\right\} = c'_{j,k} = \sum_n x'[n] g_j\left[n - 2^j k\right], \qquad b'_{J,k} = \sum_n x'[n] h_J\left[n - 2^J k\right] \tag{6.3}$$

and "wavelet coefficients" $c''_{j,k}$ $(j = 1,...J)$and scale coefficients $b''_{J,k}$ of thermal signals

$$b''_{J,k} = \sum_n x''[n] h_J\left[n - 2^J k\right]\ \mathrm{DWT}\left\{x''[n]; 2^j, k2^j\right\} = c''_{j,k} = \sum_n x''[n] g_j\left[n - 2^j k\right] \tag{6.4}$$

where $\sum_n x'[n]$ is the sum of image signal samples, $\sum_n x''[n]$ is the sum of thermal signal samples, $g_j\left[n - 2^j k\right]$ analyzing discrete small-wave function, $h_J\left[n - 2^J k\right]$ analyzing scaling function.

As a result of summing the obtained coefficients of both transformations, we get.

$$C_{j,k} = k\left\{\sum_{m=0}^{M-1}\left(c'_{j,k}\right)_m + \sum_{n=0}^{N-1}\left(c''_{j,k}\right)_n\right\} \tag{6.5}$$

The final step involves obtaining the output signal in the form of time samples, which is implemented using an inverted DVP.

$$x[n] = \sum_{j=1}^{\infty}\sum_{k\in Z} C_{j,k}g_j\left[n-2^j k\right] + \sum_{k\in Z} B_{J,k}h_J\left[n-2^J k\right] \tag{6.6}$$

The functional scheme of signal complexation is shown in fig.6:

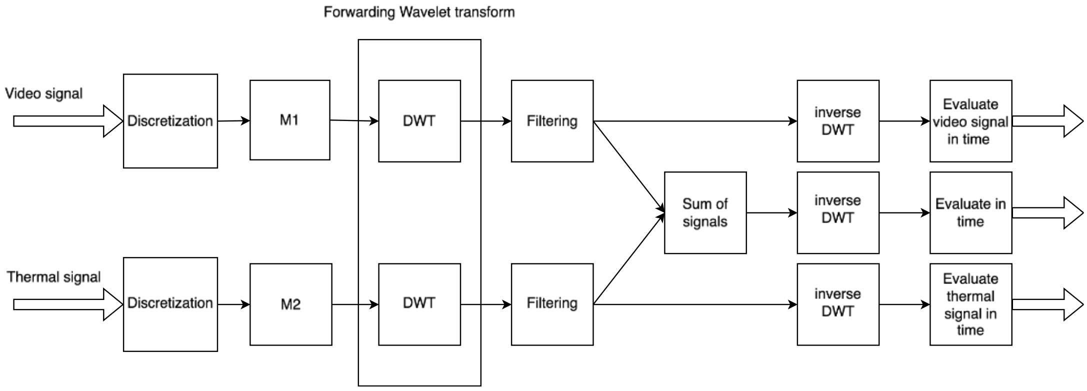

Figure 6. Functional scheme of complexation of thermal and video signals in the wavelet domain.

Since the sizes of video and thermal images do not match in the vast majority, to avoid discrepancies during superimposition, after their agreement and discretization, they must undergo mandatory scaling. The representation of both signals in the wavelet domain makes it possible not only to sum the signals in the energy domain, but also to filter them from interference and noise by discarding insignificant wavelet coefficients.

It should be noted that ensuring high quality characteristics for such a presentation is possible if the same basic wavelet function is used for both transformations. The choice of such a base function is a task for further research.

An important advantage of such integration of images and thermal signals, which have different physical origins, is that this operation takes place in the same wavelet region. In addition, the use of such a transformation allows for a more comprehensive analysis of such signals and to change their decomposition depth, which in turn makes it possible to widely influence the characteristics of the output signals.

The implementation of Recurrent Neural Networks (RNNs) in the classification of signals, including video and thermal signals, has shown promising results in various applications.

Referring to the fig.6 it is required to mention the purpose of blocks M1 and M2. They define the usage of RNN for predicting a set of parameters of the base function, for the video and thermal signals respectively. Furthermore, understanding the base functions and operations of RNNs is essential for optimizing their performance in signal classification tasks. The utilization of activation functions, loss functions, and optimization algorithms plays a critical role in training RNN models effectively.

A key aspect of using RNNs in signal classification is their ability to process sequential data, including signal variations over time, and learn complex patterns within the data. By training on labeled signal data, RNNs can effectively classify and differentiate between different signal types based on learned features.

In the context of integrating video and thermal signals, RNNs can be trained to classify specific patterns or features present in both types of signals. This approach allows for more advanced analysis and interpretation of the combined signals, leading to improved detection, recognition, and processing capabilities.

7. Prospects for further research development

To improve algorithms for combining images and infrared thermal signals, and for further research development the following approaches are additionally used.

1) Color calibration. Depending on the characteristics of specific cameras and scenes, deviations in color data transmission may occur. Therefore, a possible improvement can be achieved by calibrating the colors of the images, which allows you to even out the color balance and achieve a more accurate combination.

2) Contrast enhancement. Mostly, thermal imaging images have low contrast, which affects the quality of the combined image. Using contrast enhancement techniques such as histogram stretching, or adaptive histogram equalization can improve the quality of the composite image.

3) Adding computer vision to the algorithm can improve object recognition in the combined image. For example, contour detection, object segmentation, or classification algorithms can be applied to automatically highlight and highlight objects of interest in the combined image.

4) If processing a large volume of images, performance may be a problem. Optimizing the algorithm and using parallel computing or GPU acceleration can improve processing time and ensure smooth rendering of the combined image.

5) Using a wavelet transform to analyze and sum both signals.

The mentioned improvements can increase the quality of the complex image, improve object recognition and provide more efficient processing of large volumes of data. The specific needs and limitations of a particular application should be considered before implementing any enhancements.

8. Conclusions

The future research should focus on:

- Developing more efficient algorithms that can handle real-time processing without compromising accuracy.
- Investigating advanced synchronization methods to ensure seamless integration of video and thermal signals.
- Enhancing the robustness of thermal imaging systems to minimize the impact of external conditions on signal quality.
- Leveraging machine learning and artificial intelligence to further improve the fusion process and adapt to varying conditions dynamically.

9. Acknowledgements

The choice of a specific method of complexation depends on the specific requirements of the task. It is important to conduct research and evaluate the effectiveness of different methods based on metrics such as accuracy, sensitivity, specificity, and speed. This approach will allow you to choose the most effective method for a specific task.

When choosing a method of combining video and thermal signals, the characteristics of available equipment should also be considered. Some methods may require special equipment, such as high-resolution sensors or specialized signal processing devices. Estimating the availability and cost of such equipment is also of great importance when choosing a method.

The use of the wavelet domain for transformation and summation of both signals makes it possible not only to transform and qualitatively integrate signals in the energy domain, but also to filter them from interference and noise.

The obtained additional positive characteristics when complexing signals make it possible to increase the accuracy and reliability of object detection, reduce false positives and provide more complete and understandable information about the scene. The integration of video and thermal signals allows to increase the visual context, which contributes to the improvement of the decision-making process.

When choosing a complexing method, it is necessary to consider that some methods can be difficult to implement and require significant computing resources. In addition, there can be difficulties in matching and synchronizing data from different sources, and integrating different types of signals can be a challenge when working with different image formats and extensions.

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