Identifying Periodical Activities Independent of Video Content

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Abstract—**In this research, a completely new and accurate method has been presented for detecting periodic activities with the help of machine vision. The proposed method is independent of motion tracking complex algorithms unlike the previous strategies and it is fully independent of contents and types of activities by performing low level calculation. Not using of heavy computations while improving the ability of periodicity detection is regarded as the unique feature of this method. The use of general and flexible framework in this method causes to facilitate the machine vision periodic activities identification process.**

Index Terms—**Machine vision, periodic activities recognition, periodic motion detection, repeating activities.**

1. Introduction

Repetition and periodicity are found in many activities and processes whatever natural or manmade. Walking, flapping the wings, shaking of tree branches due to wind and the pendulum motion of the pendant are of the natural periodical activities and the motion of products on the production line of a plant or rotation of gear are of the manmade periodical activities.

Various presence of periodicity features in much motion, changes, and generally activities indicate importance of studying this feature scientifically and practically so that more attention has been paid to analysis and study of periodical activities with help of systems and software of machine vision in recent decades. Different methods have been presented for detecting and analyzing periodical activities by machine vision researchers[1]–[14]. The focus of most of these methods is on periodic motion detection and use of motion tracking algorithms while motion tracking algorithms are not applied in detection of periodic activities which are motionless such as the alternative change of objects color. The use of accessory tools and systems, such as sensors in some of previous presented methods to facilitate the periodical detection process, make these methods be single-purpose solutions.

The method presented in this paper has provided desirable conditions for the accurate analysis of these activities by excluding the above limitations and introducing a general framework for solving the periodical activities motion problem with help of machine vision.

First, we briefly study some of the performed works and we refer to their weaknesses and strengths. Then, in Section 3, we mention main concepts and mathematical definitions. Implementation and the presented algorithm are described in Section 4. Finally, Section 5 presents experimental results of applying this method.

2. Previous Researches

Among periodical activities, analyzing and detecting of human walking and running have been the main targets of most of the conducted researches[1],[3],[4]. Although periodic motion detection of human has inherent limitations[12], some of these limitations have been adjusted using modeling methods and accessory systems such as sensors and radio senders[4]. Main weakness of the methods applied in this field is the dependency of periodic motion detection on motion types. It means that we need our special software /hardware methods and equipment to detect and analyze any kind of motion[2],[3].

To overcome this weakness, other methods which detect and analyze periodic motion and activities only with the machine vision system and without help of external equipment have been presented[2],[5]–[8],[11],[13]. It is common to use the motion tracking algorithm among these methods to detect its periodicity. Two main weaknesses of these algorithms are relative complexity and more importantly, lack of applications in motionless periodic activities.

As referred in Section 1, periodic activities are not limited to periodic motion, such as periodic color change of an object, therefore, the above algorithms are not applicable under these conditions. Generally, machine vision researches and methods can be classified from different

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perspectives: the methods which detect and analyze periodic motion with help of other hardware systems (such as sensors) or directly perform this activity by analyzing and low-level comparing images[8],[11], the methods which have detected periodic motion such as [2] considering that the entire scene has not been displaced (fixed camera), the methods which have overcome this limitation by deleting the background image of the desired object[8],[13],[14], methods have tried to detect all periodic activities, and methods which have been presented only for detection of periodic motion. Main criticisms of these methods are relatively complexity, high computational overhead in periodic motion detection, carelessness in results and more importantly, dependency of detection algorithm on the subject and content of the scene. Overcoming these criticisms is our main motivation for presenting an accurate and content independent periodic motion detection algorithm in a general framework. In the next section, the term of problem and hypotheses has been defined and main concepts have been elaborated.

3. Defining Problem and Main Concept

Problem: periodic motion detection in a video file and extraction of its feature based on these hypotheses:

- Video content and subject can relate to anything.
- General position of the image relative to camera is fixed.
- The entire image zone is regarded as the desired content.
- Recording the frame rate is commensurate with the speed of periodic activity so at time of broadcasting the activity's changes are seen continuously.
- No accessory hardware is used for solving problem.

The presented method effectively and accurately satisfies conditions of the problem by analyzing low level of the image changes which guarantee its content independence. We deal with some concepts and definitions which have been used in this method.

3.1 Periodic Function and Almost-Periodic Function

In [19], the periodic function was defined as (1) where τ is the period of function:

$$\forall x:\ f(x+k\tau)=f(x),\ \ k\in Z. \tag{1}$$

Considering the definition of the periodic function, the probability of waived error percent has not been predicted and what is present in real and natural scenes and even artificial scenes is error percent probability in (1). For this reason, almost periodic functions are defined with (2) where τ is the approximate period of the function and ε is an error threshold value:

$$\forall x:|f(x+k\tau)-f(x)|\le\varepsilon,\ \ k\in Z. \tag{2}$$

It should be noted that the function which represents the periodic activity is an almost-periodic function (in the previous researches, this point has not been mentioned) which indicates high accuracy of the applied algorithm.

3.2 Periodic Motion and Periodic Activity

To emphasize distinction between the periodic motion and periodic activity, we give more accurate definitions.

A. Periodic Motion

Periodic motion means changes in geometrical position of an object or subject periodically and independently of other components shown in video. Videos containing periodic motion are subsets of videos containing periodic activities.

B. Periodic Activity

The periodic activity does not necessarily contain motion but changes may be made in colors of the image themes not their geometrical changes. In video images which contain different periodic motion, it will be impossible to track all complex motion in some cases but these complexities are avoided considering the concept of periodic activities.

3.3 Similarity Function and Similarity Matrix

Two main concepts which play the main role in periodic activity detection are the similarity function and similarity matrix.

A. Similarity Function

We define "similarity function" as Similarity(f_i, f_j), where f_i and f_j are images of two frames of a video file. The output of this function is equal to the similarity between two frames specified. On the other hand, this function should have some special features. The first and the most important feature of this function is symmetry (relation (3)). Another feature is having a bounded function range (relation (4)) and the similarity of each frame with itself will be equal to the maximum value based on the idempotency feature of the similarity function (relation (5)). The more accurate the "similarity function" is, the more accurate the period found by the entire period detection process is.

$$\text{Similarity}(f_i,\ f_j)=\text{Similarity}(f_j,\ f_i) \tag{3}$$

$$\text{MIN}\le\text{Similarity}(f_i,\ f_j)\le\text{MAX} \tag{4}$$

$$\text{Similarity}(f_i,\ f_i)=\text{MAX}. \tag{5}$$

One can use different algorithms for comparing and determining similarity between raw images of two frames. By altering image of the frames (such as bleaching, frame change, size change, colorful mapping), one can use more efficient analogy algorithms. In this research, we used two "exclusive or" and "correlation coefficient" functions for comparing frames. The "exclusive or" function uses fast logical-mathematical calculation and the “correlation coefficient” function uses accurate mathematical calculation for determining the similarity. In Section 4, we describe each one of these functions. The comparison between the output and complexity of algorithms of these functions can be a good criterion for the use of other innovations.

B. Similarity Matrix

The similarity matrix which is shown with SimMatrix [f_i, f_j] stores information about the similarity between two desirable frames. This matrix is used to analyze information particularly in the period detection stage. General structure of this matrix is shown in Table 1. Each one of the matrix entries contains the output of similarity function for two frames specified in rows and columns of the matrix.

Based on symmetrical features of similarity function, the similarity matrix will be symmetrically relative to the main diameter. Entries of the main diameter will have the maximum value. According to the definition of (almost) periodic functions, the necessary and enough condition for periodicity of the intended activity is expressed as (6) where N is the period value in unit of frames. We study the use of this relation to detect and analyze periodic activities.

$$|\text{SimMatrix}[f_i,\ f_{j+kN}]-\text{SimMatrix}[f_i,\ f_j]|\leq\varepsilon. \tag{6}$$

4. Identification of Periodic Activity

The following pseudocode indicates the general process of periodic activity detection and period extraction in a video file:

1: For every frame in the video file do;
2: SimMatrix[f_i, f_j] = Similarity(f_i, f_j);
3: Analyze SimMatrix for finding the period(s).

The complexity of this algorithm (apart from line 3) is equal to (7) where n is the total number of frames.

$$\theta(n^2-2n-1) \tag{7}$$

$$\theta\ (n^2/2-n/2) \tag{8}$$

Table 1: Similarity matrix of a video with n frames

Frame	0	1	2	3	4	5	…	n
0	1.00	0.98	0.97	0.80	0.75	0.74		0.86
1	0.98	1.00	0.95	0.74	0.72	0.61		0.97
2	0.97	0.95	1.00	0.91	0.83	0.77		0.99
3	0.80	0.74	0.91	1.00	0.99	0.92		0.95
4	0.75	0.72	0.83	0.99	1.00	0.88		0.83
5	0.74	0.61	0.77	0.92	0.88	1.00		0.70
…								
n	0.86	0.97	0.99	0.95	0.83	0.70		1.00

To decrease complexity, one can use properties of similarity matrix. For this reason, the above algorithm is corrected as follows:

1: For frame first to frame last;
2: Compare each frame with its all next frames and fill the one side of the SimMatrix triangularly;
3: Fill all cells of the diagonal with MAX(=1 here);
4: SimMatrix[f_j, f_i] = SimMatrix[f_i, f_j];
5: Analyze SimMatrix for finding the period(s).

The complexity of the above algorithm (apart from line 5) is equal to (8) which will be more suitable than the first algorithm. Full recording of similarity information in the entire matrix will facilitate its analysis process.

As mentioned in Section 3.3 A, two functions have been used in this research, which have the following features. We introduce each one of these functions.

4.1 “Exclusive or” Function

In logical operations, the “exclusive or” function is frequently used to determine equality of bit strings. Based on this capability, we apply the “exclusive or” function on two images with red-blue-green bit mapping and analyze the third image. The closer the images of two frames in terms of composition and colors are, the darker the image obtained from application of the “exclusive or” function is. Therefore, the darkness of the image can be one of the criteria for similarity of two frames. Simply, the ratio of dark (black) pixels to total pixels can be used as a numerical index. The following pseudo codes indicate how to use this function:

1: Image=$f_i \oplus f_j$;
2: Similarity(f_i, f_j)=1–(number of dark (black) picas in Image) ÷(total number of picas in Image).

Although the “exclusive or” function is not accurate enough considering the simplest calculation, hardware implementation and high execution speed are regarded as its strengths. The “exclusive or” function has the conditions mentioned in Section 3.3 A. In this regard, one can attribute values of between 0 and 1 to the similarity of two frames using it. If two frames are equal to each other, the maximum value of 1 will be obtained.

4.2 “Correlation Coefficient” Function

Generally, the word “correlation” between two or more variables and the correlation coefficient function which is shown as “correlation coefficient (f_i, f_j)” indicate intensity and type of this relationship[16]. The correlation coefficient is not only mentioned between single parameter variables but also one can determine correlation coefficients between entries, matrices, images, etc. Some image processing methods have used correlation coefficient of two images to calculate their similarities[8],[11].

Relation (9) shows the general formula for the calculation of correlation coefficient (r=correlation coefficient (x, y)).

$$r = \frac{\sum (x_i - x_{\text{mean}})(y_i - y_{\text{mean}})}{\sqrt{\sum (x_i - x_{\text{mean}})^2 \sum (y_i - y_{\text{mean}})^2}}. \quad (1)$$

In [15], the author has mentioned some computational anomalies to determine the similarity between two images. But considering the application of periodic activities detection to this function, we will not face these anomalies. The correlation coefficient also covers the desired conditions in Section 3.3 A. In this regard, output values of this function will be between 1 and −1 where 1 represents identically similar and −1 represents that frames are in contrast and zero indicates dissimilarity. The following equation shows how to calculate the similarity with help of correlation coefficient:

$$\text{Similarity } (f_i, f_j) = \text{Correlation coefficient } (f_i, f_j).$$

Diagrams obtained from applications of the correlation coefficient for periodic activities detection prove a high ability and accuracy of this function to detect very complex changes (Fig. 2 to Fig. 8). Since correlation coefficient function acts very accurately and has mathematical components which can be implemented by hardware, use of this function in periodic activity detection system will be fully justifiable. In Section 5, we analyze results obtained from applications of this function.

4.3 Calculation of Period

The period of periodic activities is equal to the period of similarity changes[8]. For this reason, one can calculate the sequence of similarity changes between one frame and other video frames of the period. In case changes of similarity between frames are identical to a fully periodic function, we will be able to calculate the period using known period extraction functions (such as the seqperiod function in MATLAB software[21]) (Fig. 2). One can adopt two different approaches toward the almost-periodic functions. In the first approach, we analyze the almost-periodic function considering the error threshold and obtain period approximately[17],[18]. In the second approach, we map almost-periodic function to a fully periodic function from the beginning and then we use the known functions to calculate the period. It is necessary to note that period recurrences occur in peaks of both main and mapped functions and this feature will be used for the generating mapped function.

5. Experimental Results

In this section, results of using the method introduced in this research have been presented to detect periodic activity on seven different videos. Each video has its own features.

Video No. 1 (colorful balls): in this video, only color changes recur periodically in some scene points (Fig. 1). So, the methods which use motion tracking algorithms are not able to detect this periodic activity. Since the correlation coefficient function calculates equal value in each period, similarities changes function will be a fully periodic function and its period will be equal to 3 frames.

Video No. 2 (pendulum simulator): the important point in this video is that the correlation coefficient function in each period produces two peaks one of which relates to return movement of pendulum. In these kinds of sweep movements, the period should be calculated considering this point (Fig. 2).

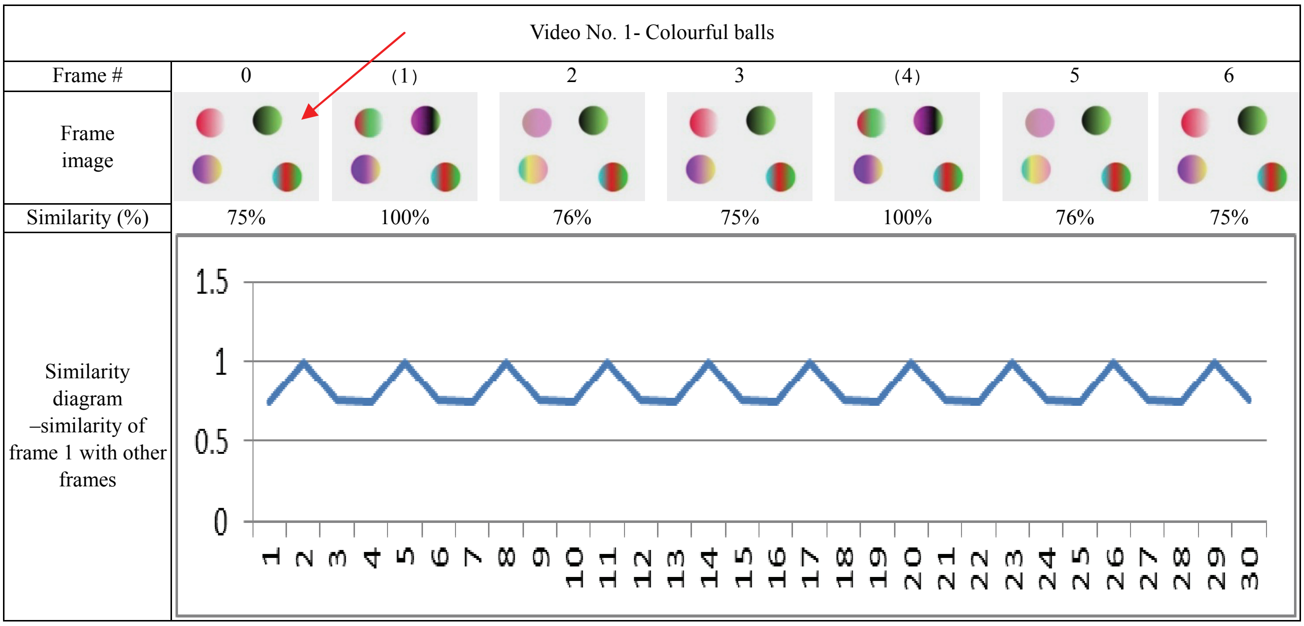


Fig. 1. In this video, objects lack geometrical motion and only their color change in each frame. Similarity function will be periodic function with period of 3 frames.

Video No. 3 (rotational movement of the earth): this video is more complex than other two videos. Here, there are no geometrical changes; therefore, one cannot use motion tracking methods (Fig. 3). Considering the output diagram, high accuracy of algorithm for detection of nonconformity of sweep scenes is evident.

Video No. 4 (pendulum motion (real)): as shown in the output diagram, the motion period has been manifested in the images similarity period (Fig. 4). Like video No. 2, it should be noted that two peaks will be created in each period one of which relates to return motion.

Video No. 5 (oil production plant): this video contains many moving objects (Fig. 5). It is almost impossible to track motion of all objects for periodic activity detection. Using the method presented in this paper, it will be very easy to detect periodicity and find its period. Based on our present knowledge, none of the past methods are able to detect the periodicity of this activity.

Video No. 6 (mineral water production plant): the unique feature of this video is fast changes of scene in addition to motion of objects (Fig. 6). This video has been recorded in low speed and as a result, high speed changes occur at time of normal speed playing. Like video No. 5, it is not possible to analyze this video through the previous methods. But this can be easily done with the help of the presented method. The diagram shows the periodic behavior.

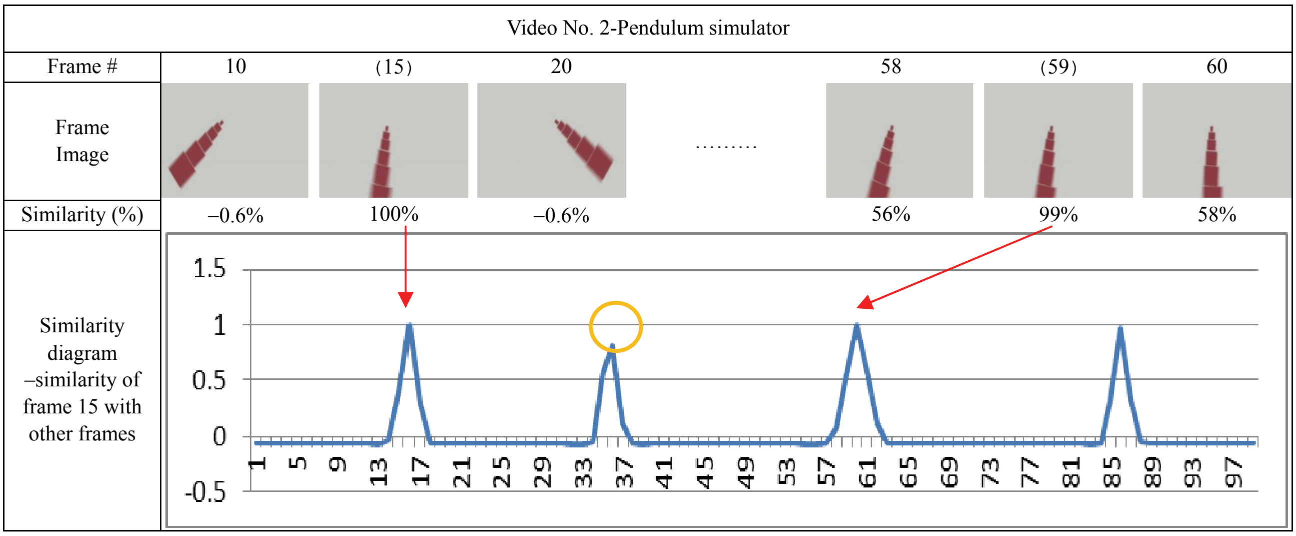


Fig. 2. In this video, there is motion of which periodicity can be detected without using motion tracking algorithms. In each period, similarity function creates two peaks one of which relates to return of motion (which is marked with a circle around it).

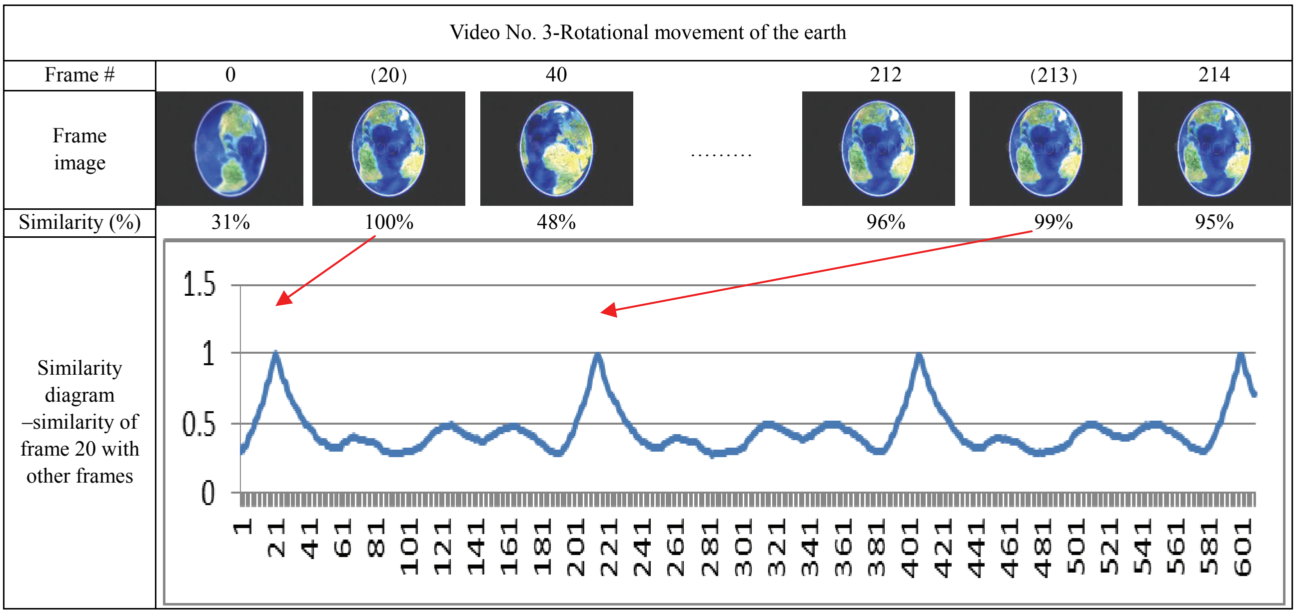


Fig. 3. Complex video which has simulated rotational motion of the earth. As observed , periodicity of this motion has been fully reflected in similarity function which is an almost-periodic function.

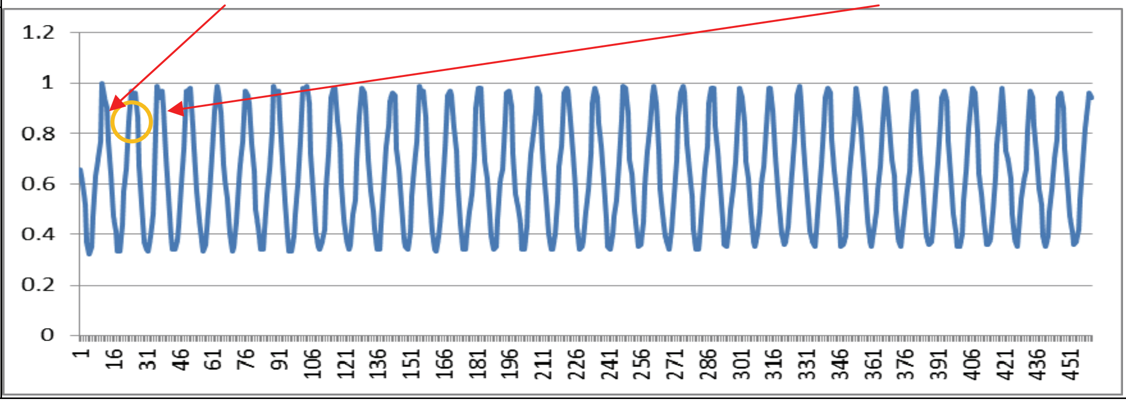
Video No. 4 (Pendulum Motion (real))							
Frame #	5	(10)	15		22	(23)	24
Frame image				………			
Similarity (%)	35%	100	47%		85%	97%	93%
Similarity diagram –similarity of frame 10 with other frames							

Fig. 4. Here, there is again a sweep motion, like video No. 2. The similarity function has recorded the pendulum motion accurately.

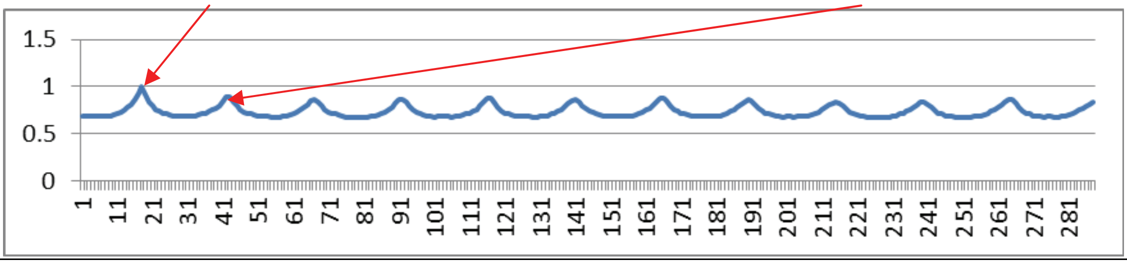
Video No. 5-Motion of oil bottle on conveyer belt (oil production plant)							
Frame #	1	(17)	33		40	(41)	42
Frame image				………			
Similarity (%)	68%	100%	70%		85%	89%	89%
Similarity diagram –similarity of frame 17 with other frames							

Fig. 5. Very complex video which includes much motion of objects which cannot be analyzed with other methods. As observed, similarity function detects periodicity of activity well.

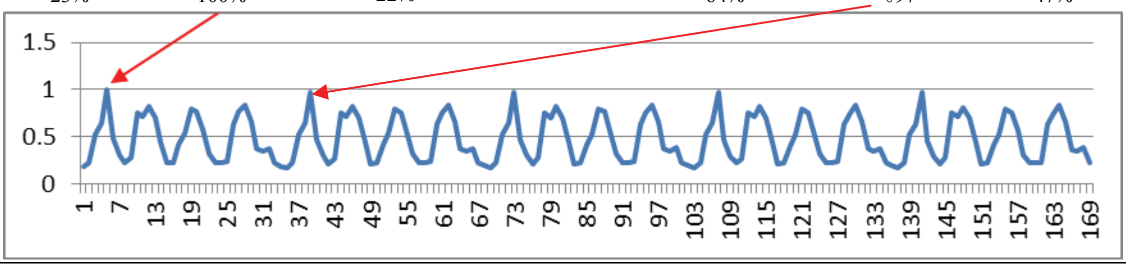
Video No. 6-Mineral water production plant							
Frame #	1	(4)	7		37	(38)	39
Frame image				………			
Similarity (%)	23%	100%	22%		64%	%97	47%
Similarity diagram –similarity of frame 4 with other frames							

Fig. 6. This video is a very complex periodic activity much faster than usual. Periodicity of activity can be detected well even despite high speed of changes.

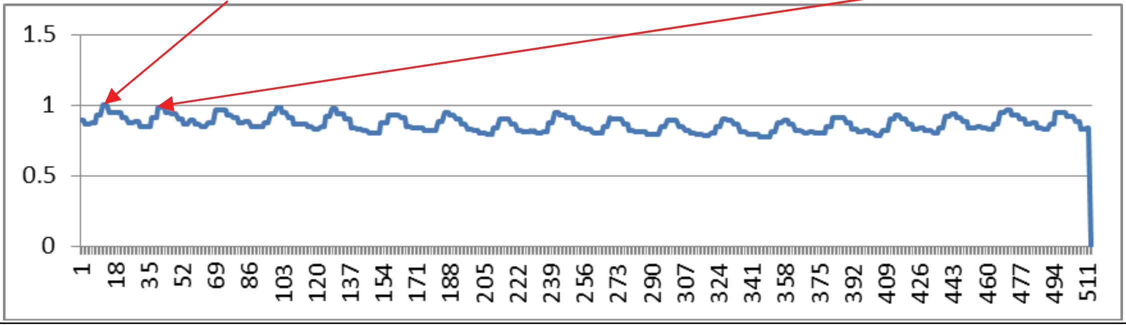
Video No. 7-Walking on treadmill							
Frame #	1	(12)	24		38	(41)	44
Frame image				………			
Similarity (%)	89%	100%	87%		91%	%98	95%
Similarity diagram –similarity of frame 12 with other frames							

Fig. 7: Activity performed in this video is almost periodic (human walking); moreover the video quality is much lower incompare with the previous samples but the algorithm is still able to detect the periodicity of it.

Video No. 7 (walking on treadmill). To compare the ability of the presented algorithm with other previous works regarding periodic motion detection, this video has been prepared and tested (Fig. 7). Despite low quality of the video, the obtained result shows the ability to use this algorithm in human walking which is an almost-periodic motion.

6. Conclusion and Future Subjects

In this paper, we present an accurate and new method for the detection of image periodic changes and extraction of its features. In comparison with other studied methods, this method is highly flexible which causes to facilitate the analysis of some complex actions and motion. The use of other functions and analysis of their efficiencies will be subjects of the future researches. Combination of this method with motion tracking methods can improve and facilitate them.

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