Fault Tolerant Control of an Industrial Manufacturing Process Using Image Processing

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***Abstract*—This paper proposes a fault-tolerant control technique, for industrial applications, based on image processing. It is known that, sensor faults disturb the normal sequences of manufacturing operations. This causes a serious delay in the manufacturing process, or even it terminated for maintenance. Cameras with ad-hoc video and image processing algorithms can be used to detect and track objects, thus they can play the role of sensors in industrial application. The proposed technique uses visual information, collected by cameras, to raise the fault-tolerant of the manufacturing system. The visual information is used to generate a redundant sensing signal to substitute the faulty-sensor signal in case of faults. The main advantages of the proposed technique are: the continuity throughout the manufacturing process as well as the detection and isolation of faulty-sensors. The proposed technique was applied to a real production line model to illustrate its performance.**

***Index Terms*—image processing, fault tolerant control, manufacturing process, fault detection**

I. Introduction

Nowadays, image processing techniques are widely used in different applications, [1-8]. Literature reviews show that, image processing and its applications in control are receiving more attention in industrial applications. Image processing of visual data was mainly used for system monitoring. Recent studies recognized the importance of visual information in process control.In fact, cameras are now used to provide visual data and non-contact measurements to be used in control of automated systems [9-16]. Analysis of visual information has been used, for example, in stability and control design, [12], [15] and [17].

Moreover, reliability and safety of systems are becoming an important addition of modern automated systems. Therefore, Fault Detection and Isolation (FDI) in systems and Fault Tolerant Control (FTC) have been analyzed, investigated and implemented in industrial processes [18-23]. Fault diagnosis (FD) in systems consists mainly from three tasks: (1) fault detection, which detect the occurrence of fault in the process, (2) fault isolation, which distinguish between different type of faults, (3) fault identification, which determine the information about the fault, i.e. magnitude, type and source of the fault. Fault diagnosis can be achieved using different techniques such as hardware redundancy, plausibility test, signal processing and model-based fault detection (software redundancy) [18].

The main objective of this paper is to introduce a new scheme for FD and FTC in the industrial manufacturing process based on image processing. The integration of visual information in FTC was proposed in [24]. The addition of a redundant sensing-component to the existing monitoring system, of an industrial production line, leads to an improvement in the reliability and monitoring of the manufacturing processes. In this research, a digital camera is used to monitor the position of a moving object that has to be processed with an industrial operating-head. The sequence of the acquired images is consequently used to decide if the object is correctly positioned or not. The incorrect positioning of the object is assumed to be caused by a fault in the operating-head sensor. The image-processing algorithm has to detect the positioning fault and send a signal, to the controller, to substitute that of the head-sensor. These actions must be done in real time to avoid the harmful consequences, of the sensor-fault, on the global operation of the industrial process. The main contributions of the proposed scheme are summarized as follows:

1) It introduces a simple and efficient technique for fault isolation based on image processing.
2) It increases the safety and reliability of manufacturing processes.
3) It provides an alternative signal for the faulty-sensor measurement based on visual information, which is very important in FTC.

The organization of this paper is as follows: Section I presents the introduction and the main objectives of this research. Section II contains the problem formulation and the basic idea of the proposed scheme which described through a motivated example of an automatic production line. The image-processing algorithm with fault tolerant control is presented in Section III. Example results are shown in Section IV. Finally, Section V presents the concluding remarks of this research work.

II. Problem Formulation

A. Basic idea

Consider the standard simple production line shown in Fig.1. It consists of a conveyor belt, an operating-head with an object detection sensor, and a digital controller. The output of the sensor and input-output signals of the controller are assumed to be 1-bit positively-encoded digital signals, i.e., 1: for activation the conveyor belt and 0: for deactivation the conveyor belt. The operation of the head is assumed to be synchronized with the controller output, which triggers the object processing-action. The processing-action requires the presence of the object, in the processing position, for a defined time-period. This must be done by the controller which monitors the production process using the sensor feedback-signal. When the processed object, located on the conveyor belt, is detected by the position sensor, the controller generates the signal that stops the moving-belt and enables the execution of the intended-action at the operating-head position. After the completion of the desired actions, the controller generates the necessary signal and the conveyor belt moves forward until the next object is detected.

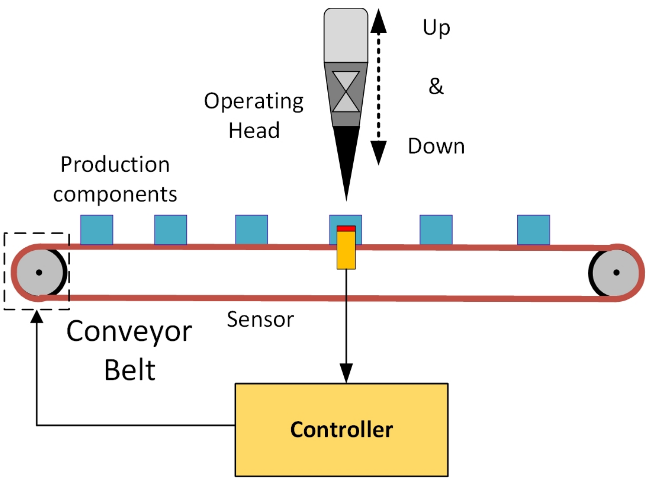

Fig. 1: Simple Industrial Production Line

Its clear that the adopted process-strategy is based on the assumption of the correct-function of the sensor. In conclusion, if a sensor-fault occurs, the synchronization of the manufacturing-process events is lost, and the visual information has to compensate for the sensor information to recover the correct flow of operations.
In this study, two sensor operations are considered. The first is the *(missed-detection operation)* where the object reaches the position of interest but is not detected by the sensor. The second is the *(false-detection operation)* in which the sensor signal shows the presence of an object while it is not-really present in the position of interest. In this case, the sensor-signal has to be driven by the output of the image processing algorithm. In both cases, if the fault persists, the algorithm generates a sensor maintenance request.

Using the visual redundant information, the maintenance can be performed during the production line operation, or it can be postponed to any desired time without stopping the manufacturing process. In fact, the manufacturing process continues to flow using the signals generated by the camera and an image processing algorithm. This makes clear that, the system uses the redundant visual based monitoring has higher fault-tolerance and reliability than the original one. In fact, the production schedule is not compromised, and the operation cost is reduced with respect to the case where the manufacturing operation is stopped for fault isolation and maintenance.
Summarizing, this paper proposes a new FTC scheme as shown in Fig.2, that integrates a digital camera, with an existing production line, to compensate for the sensing-fault problem, of a single sensor, and avoiding the consequent interruption in the work-flow of the manufacturing process.

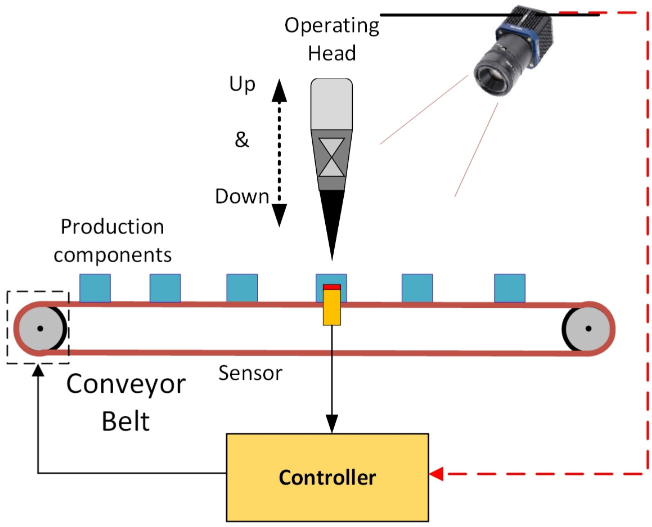

Fig. 2: Proposed Scheme on Industrial Production Line

B. Problem Formulation

To achieve the proposed scheme of integrating design, the following essential tasks should be done:

1) Apply image processing techniques to detect the positions of production components.
2) Construct a control algorithm that manages the redundant signaling sources.
3) Diagnose the persistence of the sensor fault.
4) Apply an FTC scheme.

III. Image Processing Algorithm and FTC

A. Video/Image Processing Algorithm

The camera is assumed to be fixed not mobile and located in a proper position to capture the desired operation position

and its neighborhood. The images, collected by the camera, are sent to the processing and control unit that implement the image processing algorithm and generate the redundant sensing signal. The object minimum's presence-time at the desired position, is priory assigned and is synchronized to the operations of the operating-head. The object arrival to the desired positions is detected by the head-sensor from its presence in the assigned position of interest. The sensor-signal and the signal generated from the image processing algorithm are compared. The decision criterion on the driving output signal is summarized as follows:
If both the sensor and the camera detect the presence of the object, then the sensor-signal is passed to the control unit. If the sensor-signal is activated and the Camera-Based-Signal (CBS) is deactivated, the CBS is passed to the control unit, and a fault-counter is incremented. The error is identified as a sensor false detection operation. If the sensor-signal is deactivated and the CBS is activated, the CBS is passed to the control unit and the fault counter is incremented. In this case, the fault is identified as a missed-detection operation. Finally, if the sensor-signal is deactivated and the CBS is also deactivated, then the control-unit input signal is deactivated indicating the absence of the object.

In the first three cases, the control unit generates an actuation-output to stop the moving belt (for the assigned processing time-period) and then change the signal-level to move the belt again until one of these conditions is newly detected. If the last condition is detected the belt is maintained in the moving state. Moreover, if the fault-count surpasses a predefined threshold, a maintenance fault-signal is generated and used as a flag to a maintenance-request. These alternatives are summarized in Table I.

The flow-diagram in Fig. 3 illustrates the algorithm for the detection of the presence of the object in the image Position-Of-Interest (POI). The algorithm starts with reading the image. Then it extracts the POI which is then subtracted from the background image, i.e. the POI image without the object presence. If the resulting image is black (bellow a threshold value) and remain black for a predefined time-period, then the presence of the object is detected, and the CBS is activated. Otherwise, the object is not detected, and consequently, CBS is deactivated. Fig. 4 shows the main idea of the image processing algorithm with POI.

B. Fault Tolerant Control

The fault-tolerant system is organized as the show in Fig. 3. Controller action depends mainly on the sensors measurements, and any fault in these measurements it will affect the whole process. FTC in the proposed scheme is based on redundant signal, where the control function will not be changed (i.e. simple and efficient algorithm for FTC). However, based on our algorithm a correct control signal is always supplying the control unit based on image processing.

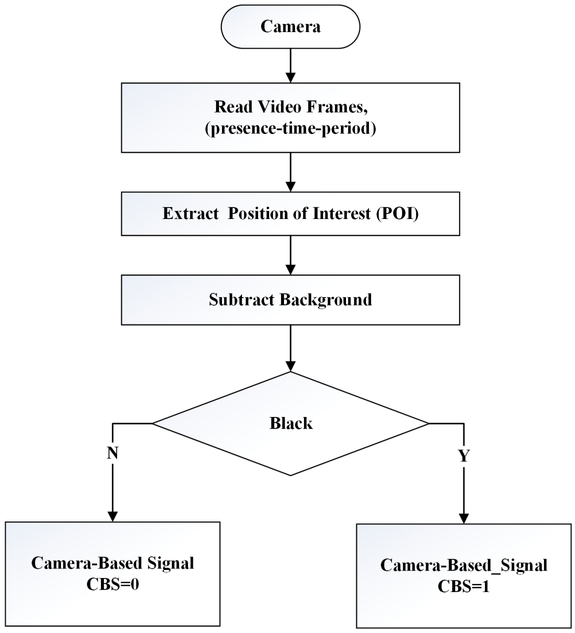

Fig. 3: Image-processing-based object presence / absence detection.

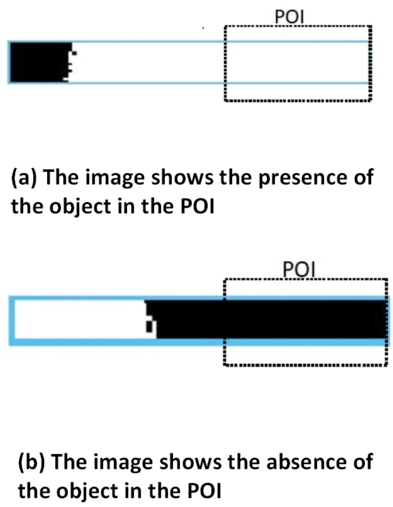

Fig. 4: (a) POI in the presence of the object, (b) POI in the absence of the object.

Table I summarize the alternatives control action between the reference signal (sensor measurement signal) and the image-processing signal (redundant signal). In addition to the control action, a monitoring system will receive a fault alarm in case of faulty sensors.

Finally, the algorithm was tested with a moving object with a production-line model.

IV. Example Results

A simple production line model, Fig. 5, was constructed to test the proposed algorithm.

TABLE I: Control-unit and monitoring system actions based on redundant signals

Sensor Signal	Image Processing Signal	Control Unit Action	Monitoring
1	1	⋆ Sensor signal is considered in the control unit.	Normal operation
1	0	⋆ Image processing signal is considered. ⋆ Sending maintenance-request.	Fault Alarm
0	1	⋆ Image processing signal is considered. ⋆ Sending maintenance-request.	Fault Alarm
0	0	⋆ Sensor signal is considered in the control unit.	Normal operation

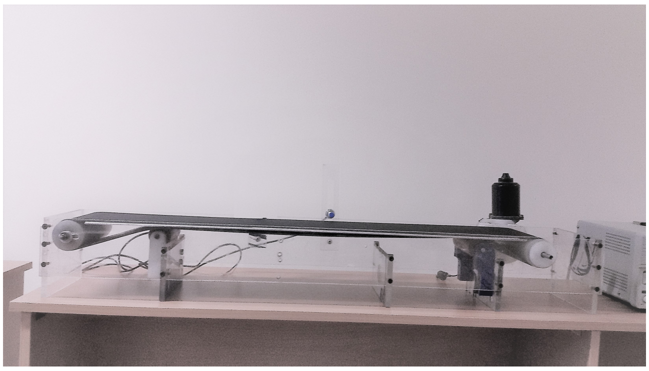

Fig. 5: Simple production line (Conveyor belt with inductive proximity sensor).

Applying the image-processing algorithm with FTC technique on the production line model with acquiring video frame rate 20 frames/sec. Fig. 6 shows the result of the video processing algorithm on the moving object. Detecting the presence / absence of a metal object is related to the number of the frame rate of the object in the POI. For example, in case of mess detection of object will pass the POI in 40 frame (i.e. 2 second). Whereas under normal operation, where the sensor detected the object, and the control stopped the belt for the assigned time, the object remained within the region of interest for 210 frames (approximately 10 seconds).

V. Conclusion

The paper proposed a simple fault-tolerant scheme to control a production line with a moving object that must be positioned in the region of an operating-head. The original system object detection is based on a position sensor. A camera was used in the control system, as a redundant monitoring element, to improve the reliability and fault tolerance of the system. Moreover, an image processing algorithm was proposed to detect the presence and absence of the object and to generate the camera-based-signal CBS. A decision criterion was also developed to manage the original sensor-signal and the CBS sources. The proposed scheme was tested with a production-line model, results showed the validity of the proposed scheme.

References

[1] R. Lerm, D. Doering, R. H. A. Rech, C. E. Pereira and A. Rettberg. A model-based design space exploration for embedded image processing in industrial applications. 12th IEEE International Conference on Industrial Informatics (INDIN), 2014.

[2] D. Aiteanu, D. Ristic and A. Graser. Content based threshold adaptation for image processing in industrial application. International Conference on Control and Automation, 2005.

[3] X. Wang, Q. C. Zhao and Q. H. Ling. Robust image processing method of laser spot center location in complex industrial environment. International Symposium on Intelligent Signal Processing and Communication Systems (ISPACS),6-9 Nov., 2017.

[4] D. Jacobsen and P. Ott. Cloud architecture for industrial image processing: platform for realtime inline quality assurance. IEEE 15th International Conference on Industrial Informatics (INDIN),24-26 July, 2017.

[5] M. P. Shleymovich, M. V. Medvedev and S. A. Lyasheva. Object detection in the images in industrial process control systems based on salient points of wavelet transform analysis. 2nd International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM),19-20 May, 2016.

[6] N. Kehtarnavaz and M. Gamadia. Real-time image and video processing. Morgan and Claypool, 2006.

[7] G.S. Virk, P.W. Wood and I.D. Durkacz. Distributed image processing for the quality control of industrial fabrics. Computing and Control Engineering Journal, Volume: 1, Issue: 6, Nov. 1990 .

[8] F.J. Dickin, B.S. Hoyle, A. Hunt, S.M. Huang, O. Ilyas, C. Lenn, R.C. Waterfall, R.A. Williams, C.G. Xie and M.S. Beck. Tomographic imaging of industrial process equipment: techniques and applications. IEE Proceedings G - Circuits, Devices and Systems, Volume: 139, Issue: 1, Feb. 1992.

[9] D. Henriksson and T. Olsson. Maximizing the use of computational resources in multi-camera feedback control. Proceedings of the 10th IEEE Real-Time and Embedded Technology and Applications Symposium (RTAS'04), 2004.

[10] F. Tombari, L. D. Stefano, S. Mattoccia and A. Galanti. Performance evaluation of robust matching measures. International Conference on Computer Vision Theory and Applications (VISAPP), 2008.

[11] Y. H. Liu, H. Wang, C. Wang, and K. K. Lam. Uncalibrated visual servoing of robots using a depth-independent interaction matrix. IEEE Transaction on Robotics, Vol. 22, No. 4, August 2006.

[12] S. M. Grigorescu and F. Moldoveanu. Controlling depth estimation for robust robotic rerception. 18th IFAC World Congress Milano (Italy), 2011.

[13] H. Wang, C. Vasseur, V. Koncar, A. Chamroo and N. Christov. Modelling and trajectory tracking control of a 2-DOF vision based inverted pendulum. Control Engineering and Applied Informatics (CEAI), Vol.12, No.3, pp. 59-66, 2010.

Fig. 6: Real object on the conveyor belt in the POI and the image-processing results from the algorithm in Fig. 3

[14] F. Janabi-Sharifi and M. Marey. A Kalman-filter-based method for pose estimation in visual servoing. IEEE Transaction on Robotics),Vol. 26, No. 5, October 2010.

[15] C. Wang, Q. Liao and Y. Mei. Dynamic feedback tracking control of nonholonomic mobile robots with unknown camera parameters. Proceedings of the 17th World Congress, Seoul, Korea, July 6-11, 2008.

[16] C. Wang, Q. Liao and Y. Mei. Natural environment modeling and fault-diagnosis for automated agricultural vehicle. Proceedings of the 17th World Congress, Seoul, Korea, July 6-11, 2008.

[17] T. Murao, H. Kawal and M. Fujita. Stabilizing predictive visual feedback control for fixed camera systems. Electronics and Communications in Japan, Vol. 129-C, No. 4, April 2009.

[18] S. X. Ding. Model-based fault diagnosis techniques: design schemes algorithms, and tools. Springer-Verlag, 2nd Edition, Berlin Heidelberg, 2013.

[19] S. X. Ding. Data-driven design of fault diagnosis and fault-tolerant control systems. Springer-Verlag, Berlin Heidelberg, 2014.

[20] A. Abdo, S. X. Ding, J. Saijai and W. Damlakhi. Fault detection for switched systems based On deterministic method. 51th IEEE CDC, Maui, Hawaii, USA, December, 2012.

[21] J. Chen and R. Patton. Robust model-based faults diagnosis for dynamic systems. Kluwer Academic Publishers, 1999.

[22] A. Abdo, S. X. Ding, J. Saijai and W. Damlakhi. Integration of residual evaluation and threshold computation into switched fault detection system. The 8th IFAC Symposium SAFEPROCSS-2012, Mexico City, Mexico, August, 2012.

[23] R. Isermann. Fault diagnosis systems. Springer, 2006.

[24] A. Abdo, J. Siam, A. Al-Rimawi Visual information integration in fault tolerant control system. 25th Mediterranean Conference on Control and Automation (MED), 2017.