Correction of the Motion Blur Alteration in the Human Lymphocyte Micro-Nucleus Image Based on Wiener's Deconvolution

Domenico Grimaldi, Francesco Lamonaca, Carmelo Macrì

Dept. of Electronics, Computer and System Sciences, University of Calabria, 87036 Rende – CS, Italy
Ph.:+39 0984 494712, Fax: +39 0984 494713, {grimaldi, f.lamonaca}@deis.unical.it

Abstract – The image correction based on the Wiener's deconvolution is proposed by evaluating the Point-Spread Function (PSF) for motion blur alteration. This correction is experimented to reduce the number of rejected images by the pre-processing procedure pointed out to correct detection of the Micro Nucleuses into human lymphocyte images acquired from the Image Flow Cytometer. The proposed correction operates in conjunction with (i) the spatial filters, pointed out to correct the bad exposure, the Gaussian out of focus and the Gaussian noise, and (ii) the Wiener's deconvolution with PSF particularized for Gaussian out of focus alteration with high intensity. The heavy computation burden of correction based on each one Wiener's deconvolution compared with that based on spatial filters suggests to use each one of the Wiener's deconvolution to process the rejected images from the spatial filters, only, and not all acquired images. According to this consideration and to speed up the complete pre-processing correction procedure, the implementation is based on the computing distributed service implemented by using the LabVIEW Shared Variables. The criteria to establish the number of PCs to be used is experimental evaluated.

I. Introduction

In [1]-[5] the corrections of different alterations affecting the acquired images of human lymphocytes flowing into the Image Flow Cytometer (IFC) [6], [7] was examined, and experimented. The alteration taken into account was (i) bad exposure, (ii) Gaussian out of focus and (iii) Gaussian noise. They are introduced by the optical and the electronic components of the acquisition system of the IFC and they (i) can misstate the image reducing the Image Quality (IQ) index, and (ii) consequently, can cause doubtful detections of Micro Nucleuses (MNs). In [1], [2] and [4] the pre-processing correction based on spatial filters before the MN detection and count was proposed. In [5] the correction based on the Wiener's deconvolution for Gaussian out of focus with high intensity was proposed with the purpose to process the rejected images by the spatial filters and to reduce the total number of the rejected images.

Recent experimental tests have highlighted that the motion blur alteration can occur when the speed of the cell in the flow chamber of the IFC is higher than that permitted by the digital camera. The previous corrections can not be able to correct conveniently this alteration. As a consequence, the MN cannot be detected by the processing procedure [3] and not for its effective absence. Consequently, the number of the images both doubtful and rejected increases.

In the paper these rejected images are taken into account with the aim to improve the correction procedure and to make it able to correct the image affected by motion blur alteration. The proposed correction procedure is always based on the Wiener's deconvolution, but the evaluation of the Point-Spread Function (PSF) of the image [8], [9] is performed by taking into account the motion angle. In order to assess that the image is altered by motion blur a proper index is defined, also.

As shown by experimental tests, this correction permits to increase the admissible range of IQ index ensuring the correct detection of the MN [4], respect to the range permitted by the correction based on spatial filters. Nevertheless, as demonstrated in the paper, the heavy computation burden compared with that of the previous procedure based on spatial filters [1], [2], [4] suggests to use the Wiener's deconvolution to process the rejected images, only, and not all the acquired images from the IFC. According to this consideration and to speed up the complete pre-processing procedure, the implementation of the correction procedure is based on the computing distributed service by using the LabVIEW Shared Variables (SV) [10]. In particular, the architecture examined refers to the computing distributed service in which the server PC performs the management of the computational load distribution among two client PCs. One client executes the correction procedure based on the spatial filters [1], [2], [4], another executes the correction based on Wiener's deconvolution for Gaussian out of focus with high intensity and motion blur. Related to the percentage of images that need the correction based on Wiener's

deconvolution, experimental tests are performed in order to asses if it is convenient to use the architecture employing two PCs, one for the spatial filters and another for the Wiener's doconvolution for the correction of both Gaussian out of focus with high intensity and motion blur, or to add another PC specialized to correct the motion blur, only.

The paper is organized as follows. The definition and the computation procedure of the index that permits to assess the image alteration caused by motion blur is shown. The correction of the images, based on the Wiener's deconvolution for Gaussian out of focus with high intensity and motion blur is presented. The aspects concerning the heavy computational burden of the Wiener's deconvolution justifying the implementation by computing distributed system are discussed. Successively, implementation guidelines of the computing distributed service are given with reference to the proposed correction procedure based on Wiener's deconvolution. In the final paper the results will be shown of experimental tests comparing the performance of different distributed architecture as regarding the speed up of the analysis time. In particular, two different architecture will be examined and compared. The former employs two client PCs, one executes the correction based on spatial filters and another that based on Wiener's deconvolution for both Gaussian out of focus with high intensity and Motion Blur. The later architecture includes another client PC executing, exclusively, the correction of the motion blur based on Wiener's deconvolution.

II. Evaluation of the image alteration caused by motion blur

In order to assess the image alteration caused by motion blur, Fig.1a), a proper index is defined. It permits to distinguish between Gaussian out of focus alteration caused by the optical and the electronic components of the acquisition system and the motion blur caused by the speed of the cell in the flow chamber of the IFC higher than that permitted by the digital camera.

The index of motion blur (I_{mb}) is evaluated on the basis of the two dimensional Fourier Transform of the altered image, Fig1b). The speed of the cell causes the non uniformity of the level curve in two conjugate direction, Fig.1c). Therefore, it is $I_{mb}= W/H$. In the case of Gaussian out of focus alteration the non uniformity of level curve is reduced and I_{mb} is approximately equal to 1.

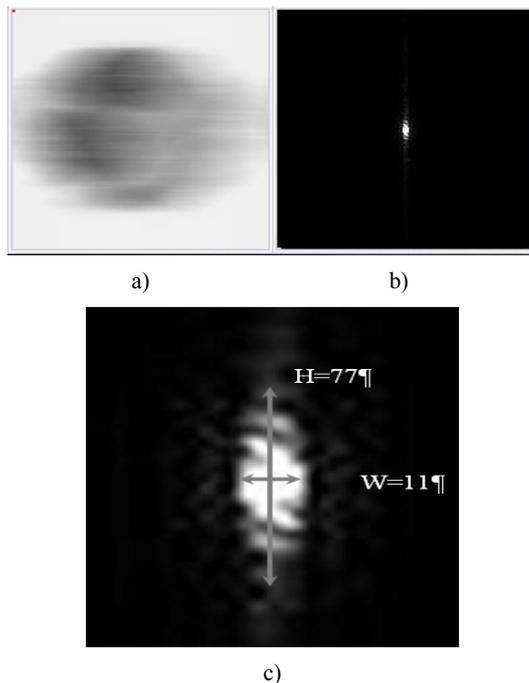a)   b)

c)

Figure 1. a) Motion blur alteration,
b) two dimensional Fourier Transform,
c) evaluation of the motion blur index.

As concerning the evaluation of the others alterations, three different IQ indexes are carried out on the basis of the three different image alterations taken into account [1], [2]. In particular:

- to detect the Gaussian noise, the mean value of the minimum values of grey levels obtained by the high pass filter applied by windowing the original image is assumed as index (IQ_{gn}),
- to detect the out of focus, the mean value of the higher values of grey levels obtained by the high pass filter applied by windowing the original image is assumed as index (IQ_{of}),
- to detect the inadequate exposure, the mean value of grey levels is assumed as index (IQ_b).

By referring to each IQ index, it must to be established if it needs (i) to correct the alteration and, successively, (ii) to process the image. The decision is carried out on the basis of the value of each IQ index compared with the admissible variation range. The lower and upper bound of the variation range is evaluated according to the characteristics of both the pattern matching analysis and blob analysis.

The index IQ_{of} can be conveniently used both in the case of Gaussian out of focus and motion blur alterations. Only the lower and upper bound of the variation range have different values.

III. Correction of contemporaneous alterations

The block scheme of the complete procedure to correct the alterations contemporaneously affecting the images, including the spatial filters and the Wiener's deconvolution, both for Gaussian out of focus with high intensity and motion blur is shown in Fig.2. Once corrected according to this block scheme, the resulting image is able to be analysed by the cascade of the pattern matching algorithm and the blob analysis to detect the presence of the MN.

For each alteration to be considered, in the block scheme two well defined processing phases are shown: (i) the "*evaluation*" of the alteration, and (ii) the "*correction*" of the alteration. In Fig.2, that based on the Wiener's deconvolution is added to the spatial filters proposed and analyzed in [1], [2] [4], and [5].

A. Correction by Wiener's deconvolution

The Wiener's deconvolution is convenient to correct the image contemporaneous altered by Gaussian out of focus with high intensity, or by motion blur. The implementation is based on the evaluation of IQ in order to determine the PSF of the image. In the case of motion blur alteration, the definition of IQ is coincident with that of IQ_{of}. For sake of clearness, IQ_{mb} is used to denote the IQ index for the motion blur alteration, and IQ_{of} for Gaussian out of focus alteration. In the case of motion blur alteration needs to evaluate the angle of the motion, also. Owing to the hardware architecture of the IFC this angle can be considered constant [6].

Denoted by G(u, v) the Fourier transform of the altered image, with (u, v) the coordinates of the transformed plan, and H(u, v) the Fourier transform of the PSF padding, the Wiener's deconvolution F(u, v) is:

$$F(u,v) = \left[\frac{1}{H(u,v)} \right] \left[\frac{|H(u,v)|^2}{|H(u,v)|^2 + K} \right] G(u,v). \tag{1}$$

The additive factor K depends on both the statistical properties of the image and the noise content. It is the ratio of the power of the image noise and the image signal. Because these powers are not usually known in practice, the additive constant is typically treated as an adjustable parameter that controls the trade-off between sharpening and noise. In the cases under examination, K is set equal to 0.9.
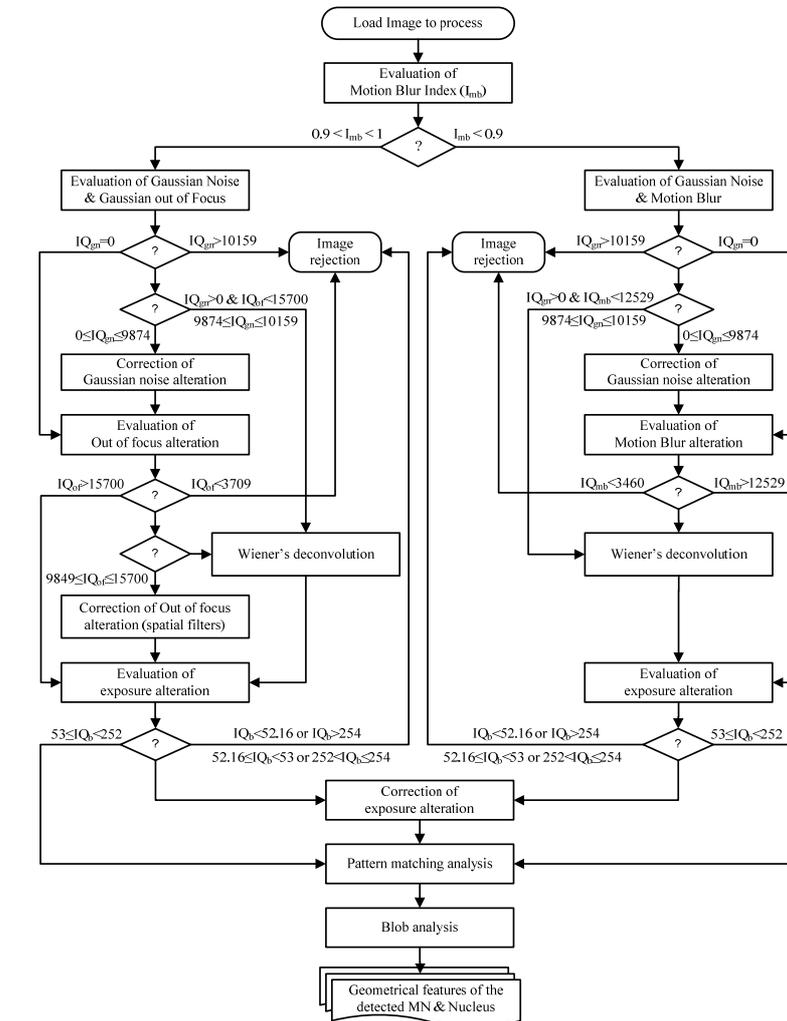

Figure 2. Block scheme of the procedure to correct the alteration contemporaneously affecting the images, based on spatial filters and the Wiener's deconvolution.

IV. Comparison among the computational burden of the correction methods

The computational burden is evaluated by referring to the original altered image with dimension NxN. As concerning the Wiener's deconvolution, the computational burden required to evaluate the PSF and the successive padding is not taken into account. Only that needed from the complex matrix operations shown in (1) is evaluated. In particular, the evaluation of G(u, v), H(u, v) and F(u, v)$^{-1}$ requires the same computational burden [8] equal to:

$$\frac{\widetilde{N}}{4}\left(2\lg_2 \widetilde{N} - 7\right) + 3 \tag{2}$$

$\widetilde{N}$ is the first power of two greater than N. The computation of

$$\left|H(u,v)\right|^2 = H(u,v)^* H(u,v) \tag{3}$$

requires $\widetilde{N}^2 + \widetilde{N}^3$ complex products, where $\widetilde{N}^2$ is the computational burden to build $H(u,v)^*$.
Therefore, the computational burden of (3) is constituted by the number of complex products equal to:

$$O_W = \widetilde{N}^3 + \widetilde{N}^2 + \frac{3}{2}\widetilde{N}\log_2 \widetilde{N} - \frac{21}{4}\widetilde{N} + 9 \quad . \tag{4}$$

As concerning the correction methods based on spatial filters of the Gaussian noise and the out of focus alteration, the computational burden is constituted by the number of real products equal to [5]:

$$O_G = 25xN^2, \quad O_{of} = 9xN^2, \tag{5}$$

for the Gaussian noise correction, and the out of focus correction, respectively. By comparing the (4) with the sum of (5) the heavy computation burden of the correction based on the Wiener's deconvolution results.

V. Distributed service architecture for image correction

Performing the correction based on the Wiener's deconvolution, the analysis time of the IFC can increase respect to that required by the correction based on the spatial filters.
Therefore, the correction procedure split in the two ways, beginning on the basis of the values of the index I_{mb}, and, successively in other two ways on the basis of the indexes IQ_{gn} and IQ_{of}, is an interesting solution. Nevertheless, performing the Wiener's deconvolution on the rejected images on a single PC can make variable in random mode the analysis time, because it is depending on the number of the rejected images.
The solution to make both constant and speed up the analysis time consists on sharing the correction procedure among several PCs. The computing distributed service can assist in testing this solution [11]-[13].
LabVIEW provides access to wide variety of technologies for creating distributed applications. Using the SV introduced in LabVIEW 8 the data can be shared between loops on a single PC or across the PC network.
The number of the acquired images by the IFC that can be processed alternatively by the spatial filters or the Wiener's deconvolution is random. In [5] experimental tests were executed to asses if it is convenient to use the architecture employing two PCs, one for the spatial filters and another for the Wiener's deconvolution for the correction of Gaussian out of focus with high intensity. In the following the results are shown of other experiments assessing the convenience to add another PC for the motion blur correction, only.

VI. Experimental tests

Fig.3 shows the computation time of the distributed service versus the image set defined in Table 1. The computational burden assigned to the PC2 and PC3 is different. In particular, Fig.3a) refers to equal number of images processed by the two PCs. Fig.3b) refers to different number of images processed by the two PCs and assigned on the basis of both the characteristics and performance of each one.

Table 1. Set of images processed on PC1, PC2 and PC3.

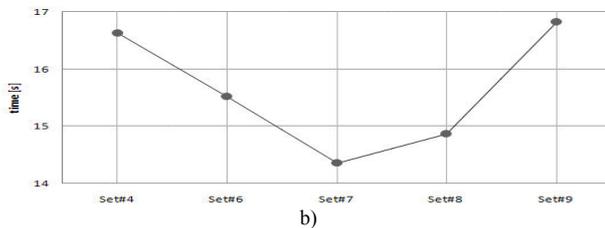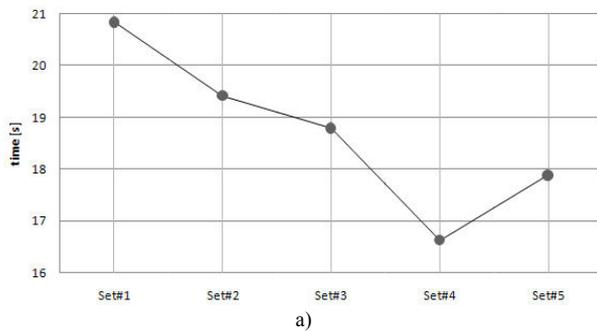| Set#	Number of altered images corrected on PC1 by spatial filters	Number of images affected by gaussian out of focus corrected on PC2 by Wiener's deconvolution	Number of images affected by motion blur corrected on PC3 by Wiener's deconvolution
1	100	0	0
2	90	5	5
3	80	10	10
4	70	15	15
5	60	20	20
6	65	15	20
7	60	15	25
8	55	15	30
9	50	15	35

Figure 3. Computation time of the distributed service versus the image set of Table 1. PC2 and PC3 process a) equal number of images, b) different number of images.

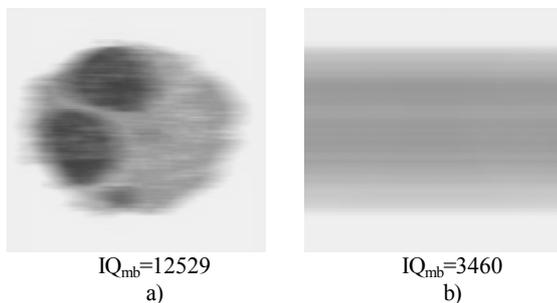$IQ_{mb}=12529$
a)

$IQ_{mb}=3460$
b)

Figure 4. Worst images altered by motion blur corrected by a) spatial filter, and b) Wiener's deconvolution.

Other experimental tests concern the evaluation of the increment of the admissible range of the values of IQ_{mb} defining the image altered by motion blur that can be corrected processed by the patter matching algorithm and the blob analysis, once corrected by the Wiener's deconvolution. Fig.4a) shows the worst images and the corresponding value of the IQ_{mb} index that can be correctly processed by the evaluation system. Fig.4b) shows the worst images and the corresponding value of the IQ_{mb} index that can be correctly processed by the evaluation system after the correction based on Wiener's deconvolution. The comparison between the values of the IQ_{mb} index highlights the reduction of the lower bound of the admissible range by using the Wiener's deconvolution.

Fig.5 shows the results obtained from the exhaustive investigation about the values of the upper bound and lower bound of the admissible variation range of all indexes IQ_{gn}, IQ_b IQ_{of} and IQ_{mb} for the correct detection of MN

VII. Conclusions

The research is devoted to reduce the number of rejected images for the correct detection of the Micro Nucleuses into human lymphocytes by means of the cascade of the pattern matching analysis and the blob analysis.

The rejection causes taken into account are the motion blur alterations affecting the acquired images by the Image Flow Cytometer, occurring when the speed of the cell in the flow chamber is higher than that permitted by the digital camera.

The reduction of the number of rejected images is achieved by the correction procedure based on Wiener's deconvolution. The heavy computational burden of this procedure suggests to use the Wiener's deconvolution to process the rejected images from the previous correction procedure based on spatial filters, only. Experimental tests confirm the fitness of the correction method.

In order to make both constant and speed up the correction procedure, the implementation by means of a distributed system is experimented.

Experimental results show: (i) the advantages of the computational distributed service, implemented by the LabVIEW shared variables, as regarding the speed up and the uniformity of the
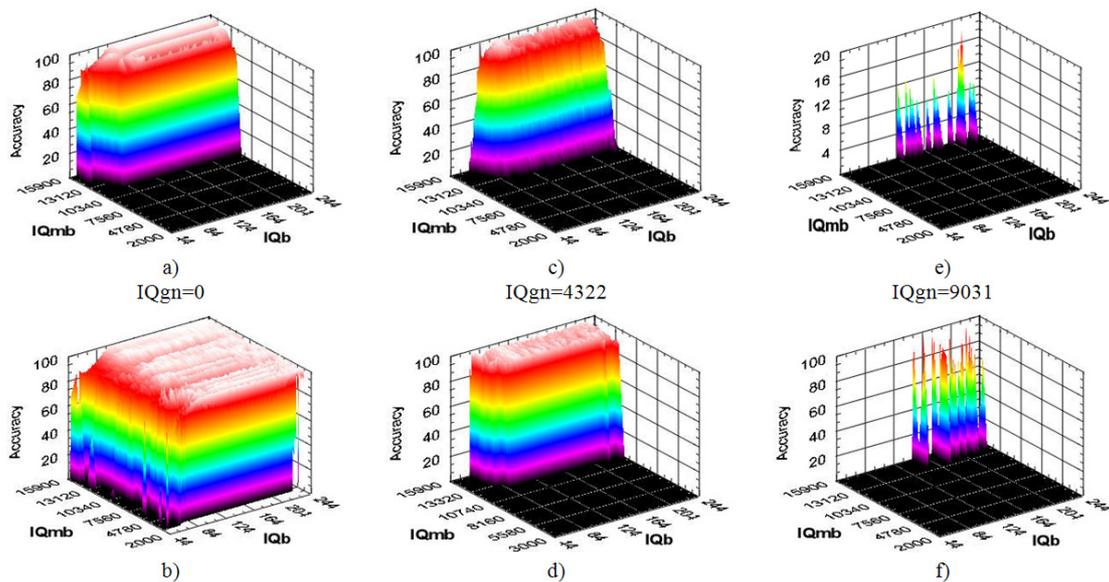
Figure 5. Regions determined by the variation range of the two indexes IQ_{mb} and IQ_b, when
IQ_{gn} has the assigned value in the case of images without correction (a, c, and e)
and images corrected by the Wiener's deconvolution (b, d, and f).

analysis time, and (ii) the enhancement of the values of the upper bound and lower bound of the admissible variation range of the Image Quality indexes.

References

[1]   D.L. Carnì, D. Grimaldi, F. Lamonaca, "Image pre-processing for micro nucleuses detection in lymphocyte", International Scientific Journal of Computing, vol.4, issue 3, 2005, p.63-69.

[2]   D.L. Carnì, D. Grimaldi, F. Lamonaca, "Pre-Processing correction for Micro Nucleus image detection affected by contemporaneous alterations", IEEE Transaction on Instrumentation and Measurement, vol. 56, No. 4, August 2007.

[3]   D. Grimaldi, F. Lamonaca, "Surface measurement of the human lymphocyte micro-nucleus in image affected by alterations", Proc of IEEE Int. Workshop on Med. Meas. and Applic., MeMeA 2007, Warsaw, Poland, 4-5 May 2007.

[4]   D. Grimaldi, F. Lamonaca, "Pre-processing of image affected by contemporaneous alterations for surface measurement of the human lymphocyte Micro-Nucleus", Proc. of IEEE International Workshop on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications, Dortmund, Germany, 6-8 Sept. 2007.

[5]   D. Grimaldi, F. Lamonaca, C. Macrì, "Reduction of doubtful detection of human lymphocyte micro-mucleus based on Wiener's deconvolution and computing distributed service", Proc. of IEEE International Workshop on Medical Measurement and Applications, MeMeA 2008, Ottawa, Canada, 9-10 May 2008.

[6]   G.F Abate, F Bavaro, G. Castello, P. Daponte, D. Grimaldi, G. Guglielmelli, U. Martinelli, F. Mauro, S. Moisa, M. Napolitano, S. Rapuano, P. Scerbo, "Tomography system to acquire 3D images of cells in laminar flow: hardware architecture", Proc of IEEE Int. Workshop on Med. Meas. and Appl., MeMeA 2006, Benevento, Italy, 20-21 April 2006.

[7]   G.F Abate, F Bavaro, G. Castello, P. Daponte, D. Grimaldi, G. Guglielmelli, U. Martinelli, F. Mauro, S. Moisa, M. Napolitano, S. Rapuano, P. Scerbo, "Tomography system to acquire 3D images of cells in laminar flow: software architecture", Proc of IEEE Int. Workshop on Med. Meas. and Appl., MeMeA 2006, Benevento, Italy, 20-21 April 2006.

[8]   J.C. Russ, The image processing Handbook, Fifth Edition, CRC, Boca Raton NW, U.S.A., 2007.

[9]   J.W. Goodman, Introduction to Fourier optics, 3rd Edition, Standford Univ., Roberts & Co., Englewood, Colorado, 2005.

[10] R. Bitter, M. Nawrocki, T. Mohiuddin, Labview: Advanced Programming Techniques, Second Edition, CRC Press, Boca Raton NW, U.S.A., 2007

[11] http://zone.ni.com/devzone/cda/tut/p/id/4679

[12] http://zone.ni.com/devzone/cda/pub/p/id/61

[13] http://zone.ni.com/devzone/cda/tut/p/id/3553#toc7