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Instantaneous Deformation Monitoring Research on the Racks in the Dense Channels Accessing-Sorting System

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Abstract

With the prosperity of e-commerce and the sharper increasing orders, the requirements of the racks' height in automatic warehouse and the weight that it can bear is higher and higher. The Dense Channels Accessing-Sorting System (Shorted as: DCASS) is a new kind of the logistic system that can be used well in the e-commerce logistic centers. For the potential hazard of racks in DCASS will be very fatal to the logistics enterprises, it is an urgent task to monitor the instantaneous deformation of racks. This essay gives an empirical research with Digital Close-Range Photogrammetric (Shorted as:DCRP) method to this problem. In the experiment, we take photos with digital cameras, and use digital analytical method to process the data that collected with computers. For the processed data has reduced the influence of outside condition and the instability of internal-external azimuth from digital cameras effectively, we get the result with precision up to 2.3%.

Keywords: *DCRP method, GM (1, 1), racks, DCASS, monitoring*

1. Introduction

Due to the increasing scarcity of human operators and the fast development of e-commerce, there is a trend towards higher levels of automation in logistic centers. As the very import part in the DCASS, racks are used for storage and load products [1]. It will be huge invested capital in warehouse development project. High-level racks play an important role on saving land, improving storage density, and reducing labor intensity [2-3]. To avoid the loss and safety hazard caused by deformation of racks, we make a feasible solution to monitor the racks instantaneously, dynamically and continuously. In this essay, we take DCRP method to monitor the deformation of racks in the DCASS, which has been used in a vast field successfully.

Considerable developments in design and operations of different types of storage systems have taken place in the last two decades, and many important models and review papers have appeared in the literature. Hassini [4-5], Litvak and Vlasiou [6] and Hassini and Vickson [7] extensively reviewed the literature and presented a general model that includes one- and two-dimensional carousel storage location problems, as well as other related problems. A carousel can be classified as an automated storage and retrieval system, which is widely used in warehousing or manufacturing. It consists of a number of racks or drawers rotating in a closed loop, operated by an on-board computer that automatically registers stock locations and items stocked, with automatic retrieval, and a picker in front of the carousel. Being made of a huge variety of configurations, sizes, and types, the carousel systems can be set horizontal or vertical, and rotate in either one or both directions. While carousel systems show space saving as a major benefit, they suffer

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from complexity in replenishments. Different from above, we will develop a series of experiment to explore the security and stability of the racks in the automated storage and retrieval systems, especially the DCASS.

As we systematically integrate digital cameras and computer to obtain, store, process, manage data and execute other duties, the speed of processing data is doubled. The images are stored stably and fixed color, which have the advantages of non-treatment, automation, real time and so on [8-9]. In the experiment, we take photos for racks monitored continuously by four digital cameras, the images are transported into computer and processed automatically, and the results will be displayed on screen, then we can get the deformation details of racks timely. It will benefit for the DCASS greatly by using our method especially when it is running. For the DCRP method can be used to monitor deformation of racks successfully in the normal weather and working conditions, and its simple and cheap devices will be helpful to improve the utilization and safety of high-level automatic warehouse, so it will be widely accepted by logistics enterprises.

In this paper, we will discuss following problems mainly:

1. The Grey Models and DCRP methods are put forward and are used in the experiments.
2. Combine with the deformation process of racks in the DCASS, the experiment data is collected and dealt with.
3. To explore a satisfying conclusion and get a result with precision to 2.3%.

2. Research Models

2.1. Grey Model

The grey theory model is a convenient method for deformation analysis; we get some satisfactory results with a little data information by using GM (1, 1) and GM (2, 1) model. The differential equations established according to the grey system theory are named GM model [10, 11]. The modeling process and principle of GM (1, 1) is as follows.

Let non-negative sequence $X_0 = \{x_0(1), x_0(2), \cdots, x_0(n)\}, x_0(k) \geq 0, k = 1,2,\cdots,n$, its generating data sequence $X_1 = \{x_1(1), x_1(2), \cdots, x_1(n)\}$, in which,

$$x_1(k) = \sum_{l=1}^{k} x_0(l), k = 1,2,\cdots,n . \tag{1}$$

Then the sequence X_1 was first-order accumulated generating sequence of X_0, named Accumulated Generating Operator denoted as 1-AGO.

Let $Z_1 = \{z_1(1), z_1(2), \cdots, z_1(n)\}$ be the tight-neighbor mean value generation sequence of X_1, in which,

$$z_1(k) = \frac{x_1(k) + x_1(k-1)}{2}, k = 2,3,\cdots,n . \tag{2}$$

then we get:

$$\textbf{GM (1, 1):}\ x_0(k) + az_1(k) = b \tag{3}$$

In which, a , b can be computed from $(a,b)^T = \left(B^T B\right)^{-1} B^T Y$, and we have:

$$Y = \begin{bmatrix} x_0(2) \\ x_0(3) \\ \vdots \\ x_0(n) \end{bmatrix}, \quad B = \begin{bmatrix} -z_1(2) & 1 \\ -z_1(3) & 1 \\ \vdots & \vdots \\ -z_1(n) & 1 \end{bmatrix}. \tag{4}$$

Then we call $\frac{dx_1}{dt} + ax_1 = b$ as grey differential equation, and the albino equation of the equation $x_0(k) + az_1(k) = b$ also named as shadow equation. The solution is:

$$\hat{x}_1(k+1) = \left(x_1(0) - \frac{b}{a} \right) e^{-ak} + \frac{b}{a}, \quad k = 1,2,\cdots,n \tag{5}$$

We also have:

$$\hat{x}_0(k+1) = \hat{x}_1(k+1) - \hat{x}_1(k), \quad k = 1,2,\cdots,n \tag{6}$$

2.2. DCRP Method

Digital Close-Range Photogrammetric (DCRP) method for adjusting digital camera is a method to establish the direct linear relation between coordinate and space position of observation points, which deal with the difference between internal-external azimuth of photos and map scale, and adjust its distortion errors. In the experiment, we usually set 16 monitoring points indoors [12]. Make the direct linear transformation as basic formulation; and the monitor points coordinate as the observation value with weight, correlative formulas of L coefficients as restrictive conditions, and indirect adjustment method with restricted conditions as adjust method of solution.

In case of given conditions, we have following formula:

$$\begin{cases} x - \dfrac{L_1X + L_2Y + L_3Z + L_4}{L_9X + L_{10}Y + L_{11}Z + 1} = 0 \\ z - \dfrac{L_5X + L_6Y + L_7Z + L_8}{L_9X + L_{10}Y + L_{11}Z + 1} = 0 \end{cases} \tag{7}$$

In the upper formula, x and z are coordinates without errors, which is a sufficient and necessary condition to create the relation between L coefficients and internal-external azimuth. After adjust the deformation of photograph negative, we can obtain the L coefficients and the approximate values of the main photograph coordinate. By monitoring points with direct linear transformation formula we can correct object distortion.

After we eliminate the system errors like the negative deformation and the object distortion, we can establish linearization of linear transformation error equation for the observation of image points coordinate. Then we have the formula:

$$\begin{pmatrix} P_1 \\ \\ P_2 \end{pmatrix} V = \begin{pmatrix} V_1 \\ V_2 \end{pmatrix} = \begin{pmatrix} M & N \\ 0 & I \end{pmatrix} \begin{pmatrix} \Delta L \\ \Delta X \end{pmatrix} - \begin{pmatrix} W_1 \\ 0 \end{pmatrix} \tag{8}$$

In which, ΔL is the correction value of monitor point coordinate; N is the coefficients of ΔL ; W_1 is constant of error equation for observation value of image points; P_1 is the observation weight value of image points; and P_2 is the observation coordinate weight value of monitor points.

In the direct linear transformation formula, there are 2 correlative formulas of 11 L coefficients. Take the two formulas as restrictive conditions when solving, then we can get the equation below:

$$A\Delta L + W_2 = 0 \tag{9}$$

In which, A is the restrictive condition coefficient; W_2 is the restrictive condition discrepancy. From equation (8) and (9), we can get:

$$\begin{pmatrix} M^T N & M^T N & A^T \\ N^T M & N^T N + P_2 & 0 \\ A & 0 & 0 \end{pmatrix} \begin{pmatrix} \Delta L \\ \Delta X \\ K \end{pmatrix} - \begin{pmatrix} M^T W_1 \\ N^T W_1 \\ -W_2 \end{pmatrix} = 0 \tag{10}$$

We take weight coefficient method to accesses the precision of any monitor elements.

$$\begin{pmatrix} X_s \\ Y_s \\ Z_s \end{pmatrix} = -\begin{pmatrix} L_1 & L_2 & L_3 \\ L_5 & L_6 & L_7 \\ L_9 & L_{10} & L_{11} \end{pmatrix}^{-1} \begin{pmatrix} L_4 \\ L_8 \\ 1 \end{pmatrix} \tag{11}$$

$$m_i = M_0 \sqrt{Q_{ij}} \tag{12}$$

In which, M_0 is the unit weights error; Q_{ij} is the weight coefficient of monitor elements.

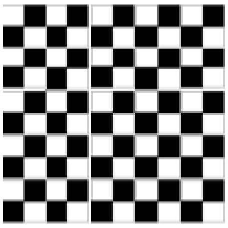

Figure 1. A kind of Cross Grid Glasses

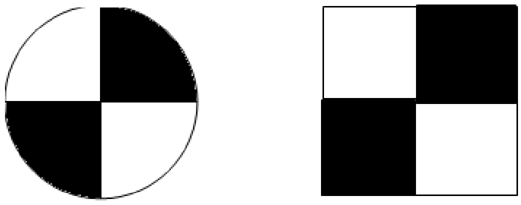

Figure 2. Images of Deformation Mark (left) and ReferenceMark (Might)

In order to improve the monitor precision of digital cameras, we took cross grid glasses which was made by ourselves, such as Figure 1, then we allocated the image points at the image coordinate system which have used the centre point of the cross grid as the origin, so as to calculate film deformation and objective distortion correctly.

This experiment shows that it is more universal than other methods to take direct linear transformation formula.

3. Two Experiments' Processes

In the twice experiments we make, the first one is under static pressure, and the second one is under dynamic condition. The first one is easy to operate, and there is fewer data to deal with; the second one is difficult to do relatively, also there is larger and complex data to process.

3.1. Static Pressure Experiment

The experiment devices are took two digital cameras which have been adjusted and one computer, and two computers installed software system which have developed by us and a printer to get the experiment results. The racks are made up of angle steel in the

DCASS as model, such as Figure 3 and Figure 4. The designed yield pressure of the rack is 140KN.

Put pressure of 50KN, 60KN, 70KN, 80KN, 100KN, 120KN on the racks step by step at first, and then reduce the pressure to 90KN, 80KN, 60KN, and give records on a board set near the rack.

In the experiment, the two digital cameras are 8m and 9m far from the rack model, and take photos when the pressure is up to the designed value, and then input the digital image into computer in time. And the software in the computer will process it quickly.

Figure 3. The Rack for the First Experiment

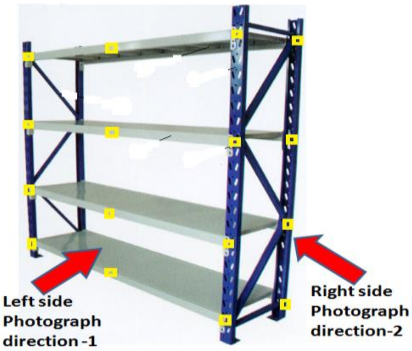

Figure 4. The Rack Model for the First Experiment

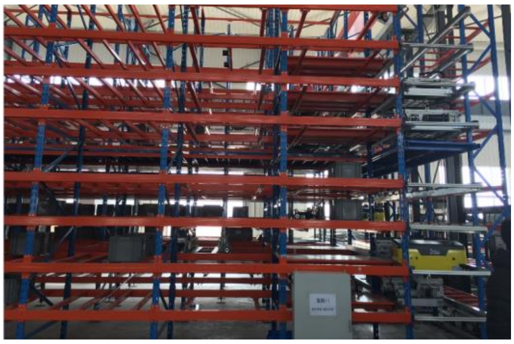

Figure 5. The Dense Channels Accessing-Sorting System

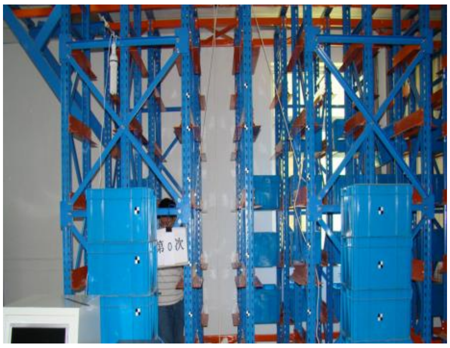

Figure 6. The Initial Image of the Second Experiment

3.2. Dynamic Experiment

The experiment devices are two digital cameras which have been adjusted, and two dumbbells (20kg, 30kg). Just like the first experiment, two computers installed software system which has developed by us and a printer to get the experiment results.

We take the second experiment in an automated storage& retrieval system of one Logistic enterprise as Figure 5. Choose a corner part of the racks made up of angle steel as model, such as Figure 6. Designed pressure is 135KN.

At first, we will let every camera take a photo before experiment as the original photos. Then we put pressure on rack slowly, use the dumbbell which impacted the rack at design angle as 20°, 45°, 60°,75°, 90°, it should fall from high position to lower freely, and the mass of dumbbell is 5kg, 10kg, 15kg step by step.

We take photos when the dynamic on goods shelf is emerged at once by the two cameras, then input the digital image into computer in time. The photo directions are set at the left side or right side of the rack (See Figure 4).

4. Data Analysis

4.1. Analysis of the First Experiment

We compare the calculated distance by direct linear transformation formula with the high-precision measured one, and then list the data as Table 1:

Table 1. Distance of the Deformation Points

point marks	U1- U2（mm）	U2-U3（mm）	U3- U4（mm）
computed distance	497	495	506
precision distance	498	495	505
errors	1	0	1

From the experiment data we get the curve map of rack deformation as Figure 7 below:

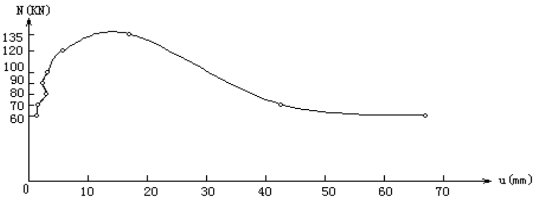

Figure 7. Load-Deflection Curve Map of Deformation

The map reflects the deformation process as the pressure is put on the rack model step by step, which is suitable for the deformation principle of the steel racks.

4.2. Data Analysis of the Second Experiment

With the following Table 2, we calculate the horizontal direction acceleration and vertical direction acceleration that impacted onto the rack.

Table 2. Vertical Direction Acceleration (impacted time is 0.2second)

Experiment times	Mass (kg)	Height (m)	Momentum (kg·m/s)	Velocity (m/s)	Acceleration (m/s^2)
1	5	1.2	24.2487	4.85	24.25
2	5	1.62	28.1745	5.63	28.15
3	5	2.1	32.078	6.42	32.1
4	10	1.2	48.4974	4.85	24.25
5	10	1.62	56.3489	5.63	28.15
6	10	2.1	64.1561	6.42	32.1
7	15	1.2	72.7461	4.85	24.25
8	15	1.62	84.5234	5.63	28.15
Experiment times	Mass (kg)	Height (m)	Momentum (kg·m/s)	Velocity (m/s)	Acceleration (m/s^2)
9	15	1.86	90.5682	6.04	30.2
10	20	1.2	96.9948	4.85	24.25
11	20	1.62	112.6978	5.63	28.15
12	20	1.86	120.7576	6.04	30.2

Table 3. Horizontal Direction Acceleration (impacted time is 0.2second)

Experiment times	Mass (kg)	Height (m)	Momentum (kg·m/s)	Velocity (m/s)	Acceleration (m/s^2)
1	10	15	10.7248	1.07	5.35
2	10	25	17.7841	1.78	8.9
3	10	35	24.7081	2.47	12.35
4	10	45	31.4443	3.14	15.7
5	10	55	37.9415	3.79	18.95

From Table 2 and Table 3, we can calculate the momentum and the force impacted onto the rack. Then we input the force value to computers, and the displacement of the deformation points displayed on the screen as Table 4. In the table, we give the real coordinate values of the reference points C_0～C_9, and deformation points U_0～U_{10}， in which the unit of the real X and Y coordinate value is mm.

Table 4. Real Coordinate Values of the Deformation Points

Load (KN)	17.5		30		35		40		45		50		55		60	
	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
C_0	849	253	852	336	867	360	838	340	812	251	788	295	865	245	954	268
C_1	848	312	850	396	866	420	837	400	811	411	787	355	865	365	955	327
C_2	847	370	849	453	865	477	836	458	810	467	786	412	866	363	961	385
C_3	843	434	844	516	860	541	831	522	805	532	781	477	859	428	949	446
C_4	839	493	841	576	856	601	827	571	802	591	777	536	855	486	943	506
C_5	96	219	99	302	114	327	85	307	60	316	35	262	113	213	203	233
C_6	96	288	99	370	116	395	86	374	59	385	37	331	116	282	204	301
C_7	96	363	100	445	114	470	85	450	60	461	37	405	116	356	205	376
C_8	99	437	101	510	116	534	87	514	62	525	37	471	116	421	205	439
C_9	99	428	100	561	116	585	88	565	62	576	37	522	115	472	207	492
U_0	583	157	585	239	600	264	571	244	546	255	522	198	599	149	689	169
U_1	582	227	585	311	599	335	570	314	545	325	522	269	599	220	687	238
U_2	580	320	582	402	597	407	568	407	543	418	516	362	598	312	687	331
U_3	577	411	579	494	594	518	565	499	540	519	516	452	595	403	685	442
U_4	576	496	578	578	595	603	565	585	539	593	515	536	595	487	685	508
U_5	554	501	556	580	571	607	542	586	517	598	495	542	573	491	660	511
U_6	480	494	482	578	498	602	469	581	443	593	418	537	498	488	586	507
U_7	452	486	454	569	470	594	441	574	415	584	392	529	471	479	559	500
U_8	454	403	456	487	472	511	442	492	416	502	393	447	471	398	560	416
U_9	555	320	556	403	572	427	544	407	417	419	494	363	473	314	658	333
U_{10}	483	318	485	402	501	425	472	306	446	415	422	359	499	310	588	329

There are so much data collected from the second experiment, so we can’t display all of them, we only cite some points which distort more obvious relatively as displayed in Figure 8.

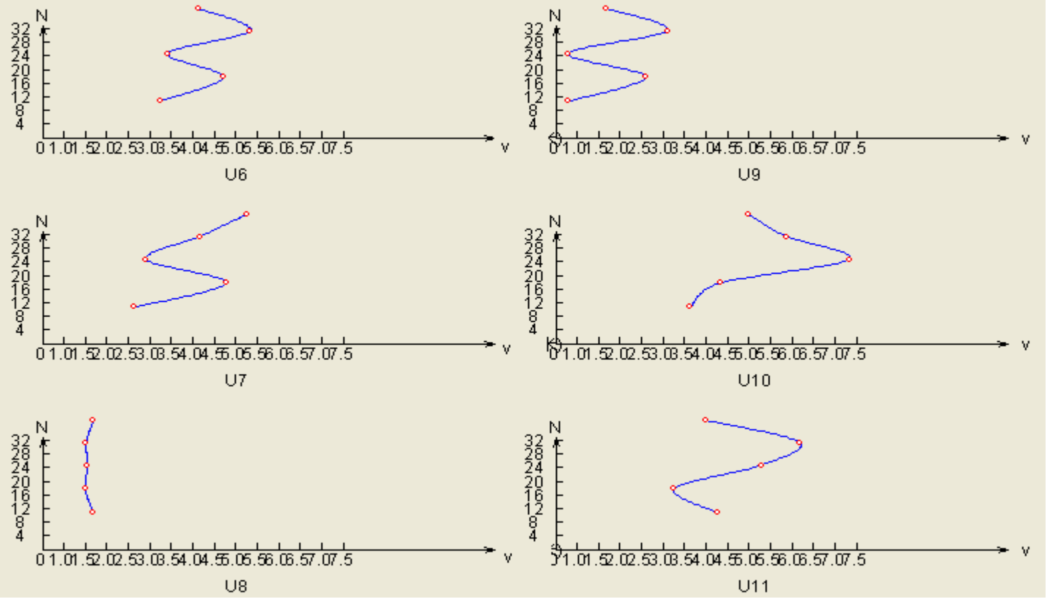

Figure 8. The Deformation Map of some Points

5. Main Conclusions

As the very import part in the DCASS, the racks are almost made of steel structure. For different kind of steel structure, the force of the steel and the performance requirements are also different. It is often accompanied by large deformation of plastic failure when the steel is damaged in force. Some cases also may be happened suddenly without any sign and obvious deformation of the brittle failure.

From the results and the deformation maps of some points in the vertical direction, we can find that steel racks' deformation vary within the elastic limit, the deformation of each point is always swinging around the center. So in the vertical direction of the experiment, the racks have deformation in the whole experiment process, but eventually returned to the original position. The racks can bear the brunt of the design standards.

For the various points in the direction of horizontal, the characteristics appear the same as the points in the vertical direction around the center, shows that the racks are stable.

There is no damage occur overall the impact of racks in the experiment. This proves the racks are stable and qualifies the rightness of the racks' displacement analysis and stability analysis. The racks can give the security and stability of items in the big earthquake motions.

The experiments show that we can obtain high precision deformation results up to 2.3% by using DCRP method. The precision result can satisfy the requirements for monitoring the deformation of racks in AS/RS systems [12-13]. The monitoring method will benefit the Logistic Warehouses such as the DCASS and others, and also bring the safety to our world when they are put in practice.

Though restricted by the properties of digital camera, and also there are some waves in the result data, we will get higher precision result in the future study when using higher resolution, larger scope optical zoom, and better optical lens digital cameras.

The DCRP method also can be applied to monitor the deformation on the large structure such as a bridge, a steel tower, and tall buildings [14]. The method can give us a convenient, cheap, and precise way to monitor the structures instantaneously, dynamically and real time.

It is difficult to reach or realize real-time monitoring during the construction process of the machinery and buildings. By using the DCRP method for the deformation monitoring, we can realize the process: data acquisition, processing and graphical display function.

Except above, we also can make the operation more convenient, efficient, and the digital cameras can be flexible placed with a certain angle, and the requirements is more looser for actual monitoring site, and make it easy to implement a remote monitoring work. By using pixels of more than 4 million digital cameras and data processing system, we can do measurement work in 60 meters.

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