Simulation of a large-scale linear move irrigator using virtual reality technology

Yuan Yanwei[1,2], Zhang Xiaochao[1,2], Zhao Huaping[1], Li Jie[1]

(1. *Institute of Mechatronics Technology and Application*, *Chinese Academy of Agricultural Mechanization Sciences*, *Beijing* 100083, *China*;
2. *The State Key Laboratory of Soil*, *Plant and Machine System Technology*, *Beijing* 100083, *China*)

Abstract: Spray irrigation is one of the effective techniques in saving water and increasing crop yield. Large-scale linear move spray irrigation systems are widely used in China. However, the traditional go-stop-go driving method causes difficulty in controlling the linear move irrigator. A new control method efficient in operation and the consumption of water, electricity, and labor is needed. Because of the difficulty in real-life examination of the designed systems, virtual reality technology was used to simulate the controlling and driving system in this study. Three-dimensional models of the irrigation system components were built at proper sizes. The three-dimensional images of the farmland as well as the mechanical models of the irrigation system were also built following the principles of ground vehicle dynamics. Application programs were developed to simulate the control system and the driving system. Through simulation an optimal control method was found, which was then used in the field test to control the large scale irrigator to move straight forward with an angle error of less than 0.06°.

Keywords: spray irrigation, linear move irrigator, walking control system, simulation, virtual reality
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1 Introduction

Spray irrigation is widely used in China[1-3] because of its high efficiency in saving water and arable land due to its channel-less design[4,5]. Compared with other spray irrigation equipment, a large scale irrigation system has the advantages of high level of automation and low consumption of power, water, and labor[6].

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Biographies: **Yuan Yanwei**, Ph.D., research interests are virtual reality and control. Institute of Mechatronics Technology and Application, Chinese Academy of Agricultural Mechanization Sciences, Beijing 100083, China. Email: yyw215@163.com; **Zhang Xiaochao**, Ph.D., research fellow, CAAMS, research interests are sensors and control system, Email: zxchao2584@163.com; **Zhao Huaping**, professor, research interests are electronics and computer application, Email: zhp2659@sina.com; **Li Jie**, M.Sc. CAAMS, Beijing, China, Email: noverage@gmail.com

A linear move irrigation system is composed of motors, joists, towers, rear suspensions, driving parts and walking components. It has high coverage rate, but has a complex structure. Thus it needs high precision synchronization of the towers, which requires an electrical driving control system to keep all the towers functioning synchronously in a horizontal line.

Studies on precision irrigation systems have been done by different researchers[7,8]. They developed variable rate center pivot irrigation control systems by Programmable Logic Controller (PLC)[9], or by addressable devices on a bus system connected to solenoid valves[10].

Precision timer was used in another site-specific irrigator to control the motors, which drove one tower to go after another. Errors had been found in the resolver angles and identified correction algorithms to get accurate field positions[11]. Although these errors are not a cause of a concern to most irrigators, accurate pivot position is required for site-specific irrigation.

A low cost GPS receiver mounted near the end of the pivot could provide a more accurate representation of the pivot's position[12]. A series of experimentation was done on automatic variable control of large scale linear irrigation systems by Zhang and partners[13] in 2001 in China. They integrated GPS technology for precision irrigation for linear move irrigator localization and navigation.

Traditional test methods to develop a synchronous control system are not only time-consuming, but also result in a waste of water, energy and cost. Based on virtual reality technology, the virtual experiment can analyze the process, performance, controlling effect of the linear move irrigation without any field test. As virtual experiments are done on a computer, the repetitions of running, detecting, and perfecting are all performed in a virtual environment, which shortens the experiment cycles and reduces water and the human resource cost[14,15]. However, few studies have been conducted on the application of virtual reality to large-scale linear move irrigation system. The objectives of this study were: 1) to build three- dimensional models of the irrigation system components according to their actual sizes, and three-dimensional images of farmland as well as mechanical models of the irrigation system following the principles of ground vehicle dynamics; 2) to simulate the control system and driving system according to real-time conditions; and 3) to conduct field tests based on the simulation results.

2 Methodology

2.1 Building 3D models

The linear move irrigator was disassembled and each part was measured. According to the measurements, 3D models of each part were built with the software of Pro/ENGINEER (2001, Parametric Technology Corporation, USA). Then the models were saved as .obj files. The .obj files were imported to Multigen Creator (MultiGen-Paradigm, USA) and the models were assembled into a whole machine with connecting joists (Figure 1).

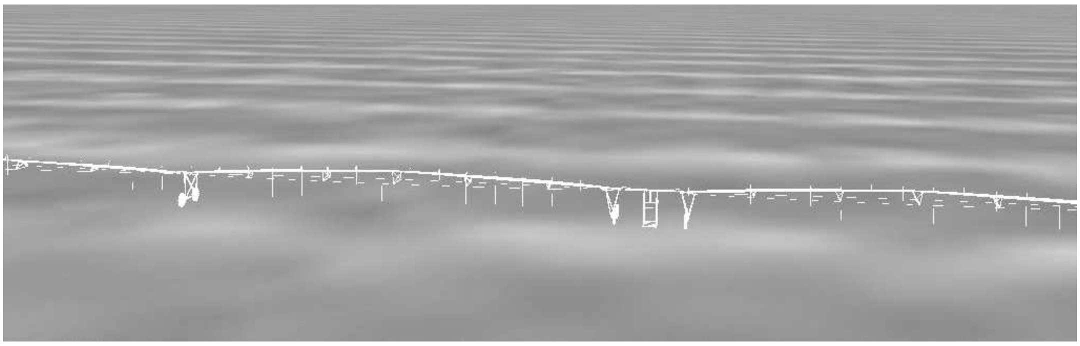

Figure 1 3-D models of a linear move irrigator

2.2 Driving of 3D models

The large scale irrigator in the study was composed of six joists, each of which was sustained by eight towers. Every tower was driven by a variant frequency motor through gear change mechanism fixed on it. A linear displacement sensor was located at every connection of two sections to detect the angle between them (Figure 1).

2.2.1 Force analysis of the irrigator tower

The linear move irrigation system consisted of towers, joists, sprinklers, cantilevers, motors, a driving system and a navigation system. Each joist was used to fix two towers. A number of cantilevers with low pressure sprinklers were fixed to a joint. Every two joists were connected by a flexible joint. A motor operated by the controlling system was placed on each tower to keep all towers move ahead in synchronization.

Since the speed of the linear move irrigator was as low as 0.03 to 0.035 m/s, it is assumed that the towers would not be transmogrified, and wheels would not be off the ground.

2.2.2 Programming of collaborative simulation

As the force, speed, position, and gesture of the irrigator are all parameters in a three-dimensional coordinate system, those parameters should be expressed as vectors. When calculating the pitch, yaw, and roll angles and positions in virtual scene, API function of Vega[16] must be used. There are four kinds of coordinates in Vega: absolute coordinates, observer coordinates, rule object coordinates, and user-defined coordinates. The position should be calculated in an absolute coordinate system, the gesture in rule object coordinates and absolute coordinates, while forces in a rule object coordinate system. Then coordinate transformation is necessary.

The gesture of the 3D model is usually described with Euler angle $(x, y, z, \theta, \psi, \phi)$, where θ, ψ and ϕ is, respectively, pitch, yaw, and roll angle that the model revolves around *x*, *y* and *z* axis. As the gimbals lock character of Euler function, when the revolving angle is near 90°, the infinite number will occur in the commutation matrix, which will terminate the simulation.

Poisson kinematics function can avoid the singularity of Euler function, but as the simulation stays, orthogonal error will accumulate. To avoid the deficiency mentioned above, quaternion was used to transform coordinates. Assuming that the vector $v=(x, y, z)$ in the 3D space correlates to quaternion $V=0+xi+yj+zk$, L being a circumrotate axis across the origin, and its orientation vector is $n=(n_1, n_2, n_3)$, then the circumvolve transformation around L for θ angle can be expressed by a quaternion as:

$$R = \cos\frac{\theta}{2} + \sin\frac{\theta}{2} n \quad (1)$$

The quaternion that V rotates θ around L is:

$$V_1 = RVR^{-1} \quad (2)$$

If L does not pass the origin and P is a point on L, we can get the transform formula through coordinate shift as:

$$V_1 = R(V - P)R^{-1} + P \quad (3)$$

The software system described in this study operates in the Windows XP operation system and Visual C++ 6.0 programming environment (Microsoft, USA). Besides, the API of Multigen Vega (MultiGen-Paradigm, USA) was also used to write programs together with C++ language to simulate the large scale linear move irrigation system incorporated between machines and the electrical controlling system. The program were embedded with the three-dimensional models of the irrigation system and virtual field scenes created with Multigen Creator (3.0, MultiGen-Paradigm, USA) software.

Console application cannot meet the requirements of the virtual reality simulation and the API of Windows is perplexing and inefficient. Thus an effective and simple method was used to program, that is, to LynX of Vega and MFC configurations to build the program.

A single document interface was built and codes were written to load the *.flt* file of the 3D models. The function *runVega*() of *myMFCVegaView* was used to check whether the ADF file has the necessary Vega class. To control the movement, we used the *input Devices* class of Vega and user-defined movement model, with *CALLBACK* function and *vgMotRegister*() to realize the control of the model. The structure vgMotionCallbackStruct was used as a parameter to transmit the motion model. Then message responding function *OnKeyDown* and *OnKeyUp* was used to receive key-press messages.

3 Simulation and field test

3.1 Collaborative simulation of machine and motors

Each motor's output power was changed by the computer keyboard, the forces of each tower were calculated according to the terrain condition and the corresponding motor driving force, and each tower's acceleration and speed were calculated[17,18]. The speed of each tower and the angles between every two conterminous joists were detected and the errors between detected and given speeds were calculated. The errors were fed back to the controlling motor[19]. The output power of each motor was changed to keep the angles between every two conterminous joists small enough. A data flow of the virtual simulation is shown in Figure 2.

As shown in Figure 2, the program is initiated with initial positions to each tower of the irrigation system. All motors fixed on each tower were started according to terrain characters, forces between other joists, weight of towers and joists, and different resistances. The positions and gestures of every tower were calculated and the scenes were refreshed.

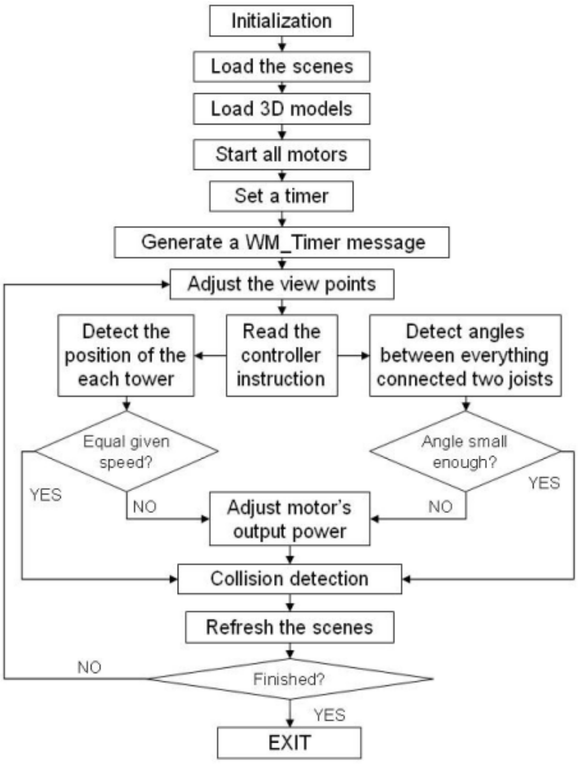

Figure 2 Data flow of virtual simulation

The angles between every two connected joists were detected and kept small enough so that all joists moved forward in a horizontal line by changing the motors' output power.

When the linear move irrigator works in the field, because of the difference in the value of gradient, soil firmness, moisture, and the glutinosity of the field, the formation of resistance is very complicated. Therefore, at different positions, random values were given as resistance.

When experimenting in virtual scenes, the eight motors started with the same frequency of 7.5 Hz and drove the wheels through derailleurs as the towers fixed on tow wheels moved ahead. However, because of the difference in resistance, the speed of each tower were different, which caused the distortion of the whole irrigation system. To correct the distortion, linear displacement sensors were used to measure the distance and angle sensors were used to detect the angles between every two connected joists. To keep all the towers in a line, the motor frequency was increased for the towers fallen behind the others, and was decreased for those in front. Simulation showed that when adjusting the angles from the middle to two directions, as being shown in figure 3, when adjusting angle a11 and angle a21, followed by angles a12 and a22, and then a13 and a23, best results were achieved.

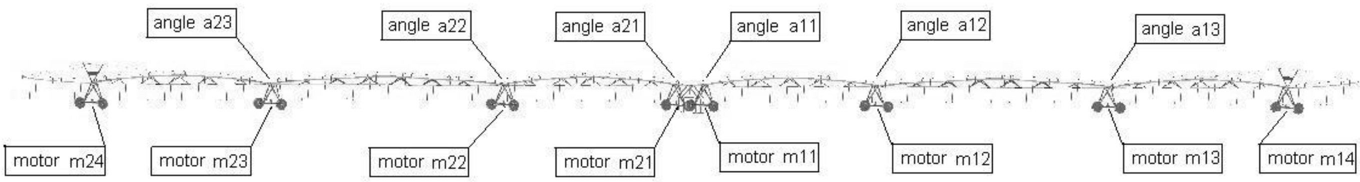

Figure 3 Angles and motors serial numbers of linear move irrigator

3.2 Field test

The field test of a linear move irrigator driving control system was conducted at the CAAMS experiment station in October 2008.

After the initialization of the system, angle sensors and frequency conversion motors were started at the same time. While the six joists moved forward together, all angle sensors detected the angles, and the frequency of every motor was adjusted to keep the whole system to operate in synchronization (Figure 4).

Ideal results were obtained as the control method concluded from the simulation was applied in the field test. Table 1 shows the angles, motor frequencies and positions of the linear move irrigation system examined in the field test.

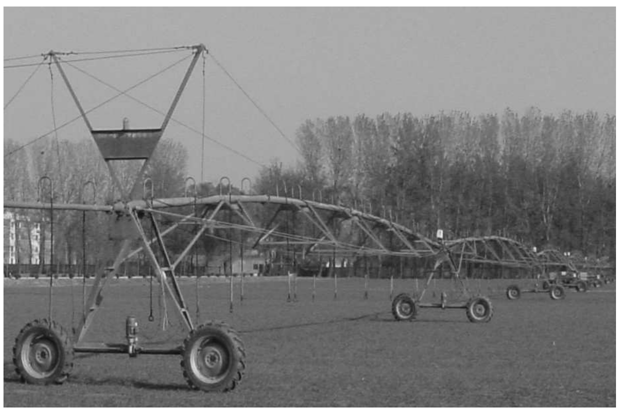

Figure 4 Synchronized control system of a linear move irrigator

Table 1 Data of an irrigator system in the field test

sample number	Angle of the sensors /(°)						Frequency of motors/Hz								Distance from field edge /m
	a11	a12	a13	a23	a22	a21	m11	m12	m13	m14	m24	m23	m22	m21	
1	0	0	-0.02	0	0	-0.02	8.99	8.29	7.73	7.63	7.12	7.35	7.13	7.29	632
2	-0.02	0	-0.04	0	0.02	0	7.84	7.90	7.48	7.01	7.31	7.57	6.51	5.81	638
3	0.04	-0.02	-0.02	0.02	0	0.04	8.41	8.05	6.99	6.20	6.81	7.36	5.85	5.09	645
4	-0.02	-0.02	-0.02	0	-0.04	-0.04	6.55	7.01	7.31	6.66	9.18	8.50	9.60	11.90	650
5	0	0	0	0.06	0	-0.02	7.22	7.64	7.20	5.23	11.59	6.95	6.59	6.71	657
6	0	0.02	0	0.04	-0.02	0	8.14	8.21	7.29	7.36	6.80	7.52	7.40	7.24	661
7	0.02	-0.02	-0.02	0.04	0.02	0	8.46	7.42	7.52	7.39	6.76	7.60	6.12	5.28	667
8	-0.02	-0.02	-0.02	0.02	0	0	7.16	7.26	7.58	7.43	7.08	7.42	6.78	6.04	673
9	-0.02	0	-0.02	0.04	0	-0.02	6.56	7.44	7.44	7.31	6.70	7.56	7.50	7.66	682
10	0	0	-0.02	0.04	0.02	0	7.87	7.89	7.39	7.25	6.87	7.61	6.31	5.93	686
11	0	-0.02	-0.04	0.02	0.02	0	7.31	6.97	7.59	7.20	7.02	7.41	6.43	6.21	691
12	-0.02	-0.02	-0.02	0.02	0	-0.02	7.26	7.48	7.52	7.34	6.86	7.48	7.14	7.16	692
13	0	0	0	0.04	0	-0.02	7.79	7.69	7.45	7.50	6.68	7.55	6.99	7.17	694
14	0	-0.02	0	0.02	0.02	0	7.49	6.89	7.47	7.39	6.82	7.53	6.43	6.19	699
15	0	0	-0.02	0	0	0	7.67	7.51	7.49	7.34	7.25	7.51	6.73	6.65	704

The frequencies of each motor changed according to the corresponding angle, to increase or decrease the speed in order to keep all joists and towers in a horizontal line. Data in Table 1 show that the linear move irrigator moved from the position of 632 meters to 704 meters, and during the whole 72-m process, the largest angle error was 0.06°.

4 Conclusions

To improve the traditional irrigation experiment method, a large-scale linear move irrigation virtual simulation system was developed. Through experiments and analysis the following conclusions were obtained: (1) Virtual models can simulate actual experiments expediently on computer; (2) simulation results show that when the angles are adjusted from the middle to both sides, the best synchronization results can be obtained; and (3) When the control method derived from the virtual simulation was implemented into the field test, the large-scale irrigation system could move almost in a straight line with an angle error of less than 0.06°.

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