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

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Abstract: Spray Irrigation is more effective for saving water and increasing crop yield than other irrigation methods. Large-scale linear move spray irrigation systems are widely used in China. But the traditional go-stop-go driving method makes the linear move irrigator hard to be controlled. Therefore, a new control method with high efficiency in operation and low consumption in water, electricity and human resource is needed. Because of the difficulty in direct examination of actual systems, virtual reality technology was used to simulate the controlling and driving system in this study. Three-dimension models of the irrigation system components were built according to their scale, and three-dimensional scenes of farmland as well as mechanical models of the irrigation system were also built according to the principles of ground vehicle dynamics. Application programs were developed to simulate the control system and drive system. Through simulation a better control method was achieved, which was then used in field test to control the large scale irrigator to move ahead in a straight line, with an angle error less than 0.06°.

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

1 Introductions

Spray irrigation is widely used in China[1-3] because of its high efficiency in saving water. Also because a channel is not needed, it can conserve arable land[4,5]. Compared with other spray irrigation equipment, a large scale irrigation system has the characters of high level of automation and low consumption of electricity energy, water and human resource[6].

A linear move irrigation system is composed of motors, joists, towers, rear suspensions, driving parts and walking components. It has higher coverage rate, but more complex structure, and needs a higher precision synchronization of the towers, so an electrical driving control system is needed to keep all towers go ahead synchronously in a horizontal line.

Research projects 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]. Though these errors are not a cause for concern for 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]. Much experimentation has been done on automatic variable control of large scale linear irrigation systems by Zhang et al[13]. since 2001 in China.

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They integrated GPS technology for precision irrigation for linear move irrigator localization and navigation.

Traditional test methods to develop a synchronous control system not only prolong the periods, but also result in waste of water, energy and financial resources. Base on virtual reality technology, the virtual experiment can analyze the process, performance, controlling effect of the linear move irrigation without field test. As virtual experiments are done on a computer, the repeating running, detecting, and perfecting are all performed on a virtual environment, which shortens the experiment periods and reduces water and human resource cost[14,15]. However, few studies have been conducted on the application of virtual reality into 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 scale, and three-dimensional scenes of farmland as well as mechanical models of the irrigation system according to the principles of ground vehicle dynamics; 2) to simulate the control system and drive system according to real-time conditions; and 3) to conduct field test 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), and then the models were saved as files of .obj formats. The .obj files were imported to Multigen Creator (MultiGen-Paradigm, USA) and the models were assembled as a whole machine with connecting joists (Figure 1).

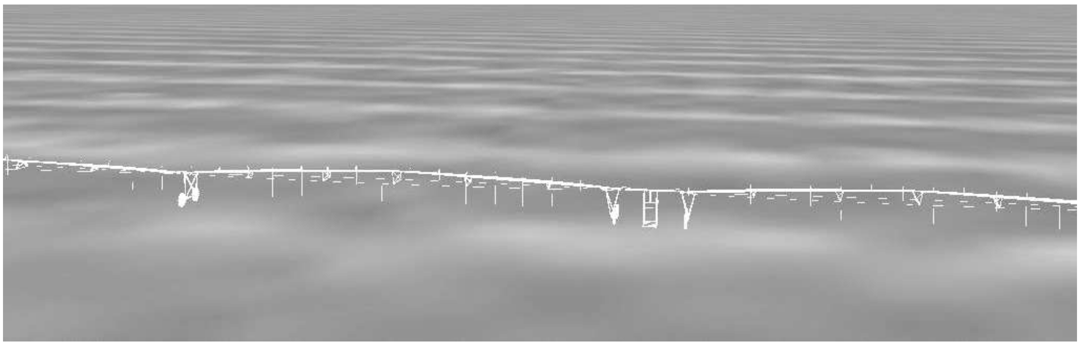

Figure 1 3-D models of a linear move irrigator

2.2 Driving of 3D models

The large scale irrigator we studied was composed of six joists, which were sustained by eight towers respectively. Each tower was driven by a variant frequency motor through gear change mechanism fixed on it. On each connection of every two connected sections, there was one linear displacement sensor 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 fixed on tow towers, and there were many cantilevers with low pressure sprinklers fixed to a joint. Every two joists were connected by a flexible joining. On each tower there was a motor, which was controlled by the controlling system to keep all towers move ahead in synchronization.

As the speed of the linear move irrigator was very low, between 0.03 m/s and 0.035 m/s, we 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 should be calculated in rule object coordinates and absolute coordinates, while forces should be calculated 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 goes on, orthogonal error will be accumulated. To avoid the insufficiency mentioned above, quaternion was used to transform coordinates. Suppose the vector $v=(x, y, z)$ in the 3D space is corresponding to quaternion $V=0+xi+yj+zk$, and L is 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:

$$R = \cos\frac{\theta}{2} + \sin\frac{\theta}{2} n \tag{1}$$

The quaternion that V rotates θ around L is:

$$V_1 = RVR^{-1} \tag{2}$$

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

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

The software system described in this study is running 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. In the program, we imported the three dimension models of the irrigation system and virtual field scenes created with Multigen Creator (3.0, MultiGen-Paradigm, USA) software.

Console application cannot satisfy the request of virtual reality simulation and the API of Windows is perplexing and inefficient, so we used an effective and simple method 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.

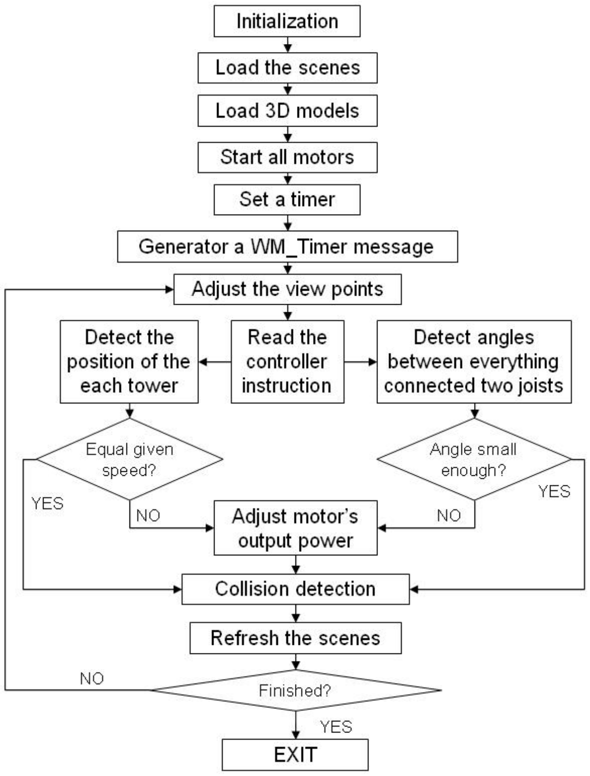

Figure 2 Data flow of virtual simulation

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

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

When experimenting in virtual scenes, the eight motors start with the same frequency of 7.5 Hz and drive the wheels through derailleurs, and the towers fixed on tow wheels move ahead. However, because of the difference of resistance, the speed of each tower is 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 whose position is behind others, and decreased for the towers whose position is ahead. Simulation showed that when adjusting the angles from the middle to two sides, as shown in figure 3, when adjusting angle a11 and angle a21, followed by angles a12 and a22, and then a13 and a23, we could get best results.

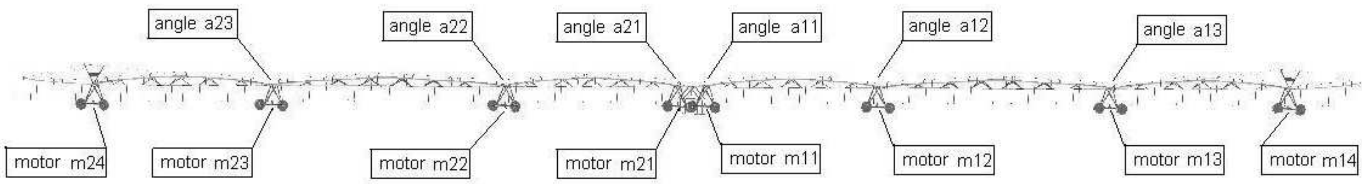

Figure 3 Angles and motors serial numbers of linear move irrigator

3.2 Field test

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

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

Then the control method from simulation was used in the field test and good results were obtained. Table 1 shows the angles, motor frequencies and positions of the linear move irrigation system used in the field test.

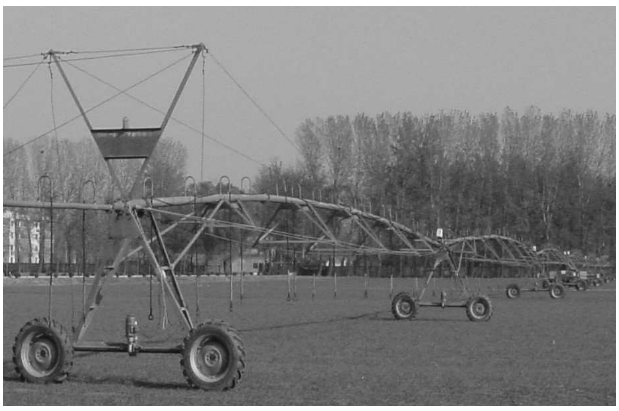

Figure 4 Synchronized control system of a linear move irrigator

Table 1 Data of an irrigator system in field test

sample number	Angle of the sensors /(°)						Frequency of motors /Hz								Distance from field edge(meter)
	a11	a12	a13	a23	a22	a21	m11	m12	m13	m14	m24	m23	m22	m21	
1	0	0	-.02	0	0	-.02	8.99	8.29	7.73	7.63	7.12	7.35	7.13	7.29	632
2	-.02	0	-.04	0	.02	0	7.84	7.9	7.48	7.01	7.31	7.57	6.51	5.81	638
3	.04	-.02	-.02	.02	0	.04	8.41	8.05	6.99	6.2	6.81	7.36	5.85	5.09	645
4	-.02	-.02	-.02	0	-.04	-.04	6.55	7.01	7.31	6.66	9.18	8.5	9.6	11.9	650
5	0	0	0	.06	0	-.02	7.22	7.64	7.2	5.23	11.59	6.95	6.59	6.71	657
6	0	.02	0	.04	-.02	0	8.14	8.21	7.29	7.36	6.8	7.52	7.4	7.24	661
7	.02	-.02	-.02	.04	.02	0	8.46	7.42	7.52	7.39	6.76	7.6	6.12	5.28	667
8	-.02	-.02	-.02	.02	0	0	7.16	7.26	7.58	7.43	7.08	7.42	6.78	6.04	673
9	-.02	0	-.02	.04	0	-.02	6.56	7.44	7.44	7.31	6.7	7.56	7.5	7.66	682
10	0	0	-.02	.04	.02	0	7.87	7.89	7.39	7.25	6.87	7.61	6.31	5.93	686
11	0	-.02	-.04	.02	.02	0	7.31	6.97	7.59	7.2	7.02	7.41	6.43	6.21	691
12	-.02	-.02	-.02	.02	0	-.02	7.26	7.48	7.52	7.34	6.86	7.48	7.14	7.16	692
13	0	0	0	.04	0	-.02	7.79	7.69	7.45	7.5	6.68	7.55	6.99	7.17	694
14	0	-.02	0	.02	.02	0	7.49	6.89	7.47	7.39	6.82	7.53	6.43	6.19	699
15	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 so as to keep all joists and towers in a horizontal line. Data in table 1 shows 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, we developed a large scale linear move irrigation virtual simulation system. Through the experiment and analysis we obtained the following conclusions: (1) This virtual system can simulate actual experiment conditions expediently on computer; (2) simulation results show that when the angles are adjusted from the middle to both sides, best synchronization results can be obtained; and (3) When the control method derived from the virtual simulation was implemented into 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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