MEMO

Subject: Image Processing

Synopsis:

The purpose of this lab is to understand basic concept of image processing in biomedical engineering laboratories. In biomedical engineering fields, image processing is very important to analyze 2-D or 3-D motions such as gait analysis, range of motion analysis, etc. Therefore, this lab helps students to learn basic proficiency in the use of digital imaging. Also, the lab demonstrates the ability of an image processing system to analyze simple 2-D motion.

There are two different motions are analyzed by imaging processing; simple harmonic motion (pendulum), combined motion (disk rolling down incline). Before performing the experiment, image calibration is critical. On the board, there are nine markers to measure actual distance and to measure by pixels through an image. Even though image calibration was carefully done, results, translational velocity vs. time, angular velocity vs. time, angular acceleration vs. time, and translational acceleration vs. time show different from expected output. This is caused by concave lens, low resolution, and not fast enough recording rate of camera. After calibration, record simple harmonic motion which starts from approximately 30 degrees. Let the pendulum hang unperturbed for a moment or two for allowing determine the natural position and point of reference for calculating angles. Now pull the pendulum 60 degrees away from vertical and release. Record this and repeat the video acquisition. Combined motion is starts with rolling a disk down incline. Be aware that simply release the disk. Then process the data with rate, 30 frames per seconds.

Equation:

$x = A\cos(\omega t + \delta)$ X = position, A= amplitude, ω=angular frequency, δ is the phase constant.

F (Frequency) = 1/ T(period)

$\alpha = \frac{d^2 x}{dt^2} = -\omega^2 x$

Angular frequency $\omega = \sqrt{g/l}$ **=** **(**32.2 ft/s^2 / (51.25 in / 12 in/ft))$^{1/2}$ =2.75 1/ s

Period with theta vs. time graph is 1.5 seconds.

Angular frequency $\omega = \sqrt{2\pi/T}$ **=** (2π/1.5s)$^{1/2}$ = 2.05 1/s

Angular acceleration $\alpha = \frac{\tau}{I} = \frac{-mgl\sin\theta}{ml^2} = \frac{-g\sin\theta}{l}$ = (-32.2 ft/s^2 sin(40))/ (51.25 in / 12 in/ft))$^{1/2}$

Result

Image Calibration

Table 1. The percent error in measurement

Placement of marker	Percent error
Near the bottom of the field of view	72.9%
Near the top of the field of view	73.8%
Near the left side of the field of view	72.9%
Near right side of the field of view	73.4%

Pendulum

Diagram 1. Free-body diagram of the simple pendulum

Angular frequency $\omega = \sqrt{g/l}$ **=** **(**32.2 ft/s^2 / (51.25 in / 12 in/ft))$^{1/2}$ =2.75 1/ s

Period with theta vs. time graph is 1.5 seconds.

Angular frequency $\omega = \sqrt{2\pi/T}$ **=** (2π/1.5s)$^{1/2}$ = 2.05 1/s

Angular acceleration $\alpha = \frac{\tau}{I} = \frac{-mgl\sin\theta}{ml^2} = \frac{-g\sin\theta}{l}$ = (-32.2 ft/s^2 sin(40))/ (51.25 in / 12 in/ft))$^{1/2}$

Table 2. Angular acceleration

Image	Angular acceleration rad/s^2
1	-4.669053178
2	-1.692222748
3	-4.321513984
4	-4.240993066
5	-1.628588681
6	-4.86639816
7	-1.819243588
8	-4.009024081
9	-4.13880168
10	-0.555046296
11	-4.61259575
12	-2.625569105
13	-3.232722922
14	-4.441769916
15	-1.628588681

Rolling disk down incline

Diagram 2. Fee body diagram of the disk rolling

Table 3. Angular acceleration

Image	Angular acceleration rad/s^2
1	4.76449352
2	-0.57972141
3	0.21090879
4	7.40880064
5	3.8072869
6	3.65552682
7	6.61261265
8	7.81116498
9	-0.90531007
10	-7.15730732
11	4.76449352
12	-0.57972141
13	0.21090879
14	7.40880064
15	3.8072869

Discussion and Conclusion

1. There is a significant difference in direct measurement and gathered with digital camera. It is due to the concave lens of camera.

2. Angular velocity is the first derivative of angular displacement respect to time and angular acceleration is the first derivative of the angular velocity respect to time. Therefore, angular acceleration is second derivative of angular displacement respect to time. Simplified formula of angular velocity is $\omega = \Delta\theta$ (Changing angular displacement) /Δt(Changing time) and angular acceleration is $\alpha = \Delta\omega$(Changing angular velocity)/ Δt (Changing time)

3. Translational and angular velocity followed expected trend in other words, direction. Translational velocity increases as time increases but it does not show a linear relationship. The linear relationship is expected for translational velocity because translational displacement is directly proportional to the translational velocity. The linear relationship is expected for angular velocity as well because angular velocity is equal to a multiplication of translational velocity and radius. Radius is constant so that angular velocity vs. time graph which oscillates respect to time does not follow expected results.

Angular acceleration and linear acceleration both should be constant due to the first derivative relationship respect to time which is a slope of angular or translational velocity vs. time graphs. However, angular acceleration and translational acceleration are both oscillate.

Possible errors would be the calculating distance by position of markers and camera. Camera which has a concave lens can cause errors during process of converting real image to a picture image. In the process of getting the position of markers with pointer, it can cause a measurement error and low precision due to sensitivity of pointer of mouse and pixel values of images.

4. During the lab, the group had problems with collecting data due to formulas are very sensitive to values which were calculated from pixel values. For example, to calculate angle, trigonometry functions are used and it is very sensitive to input values as angle which is calculated from collected data with pixel positions.

It would be better to have more than one camera especially for 3-D motion analysis. Then it can be calibrated to have more precise data. When three cameras are placed with three different axis, it can give a good analysis of motions with three different views.

It would be a good idea to use a device which measure durational time during an object is passing gates. Then it is possible to measure a real distance between two gates and time is measured by a device. This gives velocity and it will also help to calculate acceleration.

It would be better to use a camera which has better resolution or faster recording rate.

This lab is satisfactory since the results of experiment were very different from expected ones. However, students understood basic concept of image processing in biomedical engineering laboratories. There were two different motions are analyzed by imaging processing; simple harmonic motion (pendulum), combined motion (disk rolling down incline). Even though image calibration was carefully done, results, translational velocity vs. time, angular velocity vs. time, angular acceleration vs. time, and translational acceleration vs. time show different from expected output. This is caused by concave lens, low resolution, and not fast enough recording rate of camera. The limitations of the lab were limited recording rate of camera and converting error from concave lens of camera. It would be better to have more than one camera especially for 3-D motion analysis. In addition, it would be better to use a camera which has better resolution or faster recording rate.

Reference

[1] Dr. Harris, Biomechanical Laboratory Lab manual. 2006

Appendix A. Diagram of markers

Appendix B. Actual measurement of markers from marker #1

Marker Locations Using Tape Measurer (in)							
Marker #1		**Marker #2**		**Marker #3**		**Marker #4**	
x	**y**	**x**	**y**	**x**	**y**	**x**	**y**
0	0	0	45	15.5	31.5	31.25	10.5

Marker #5		**Marker #6**		**Marker #7**		**Marker #8**	
x	**y**	**x**	**y**	**x**	**y**	**x**	**y**
50.25	17.5	54.75	32.5	71.3	28.25	75.75	7.5

Appendix C. Screen shot of Microsoft Excel program

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	
1		pixels/ft	pixels/in	origin															
2	board	47	3.9166667	x	y														
3	pendulum	50.57	4.2141667	99	106.00														
4	disk	49.7	4.1416667																
5																			
6		Four Corners of Image (Pixels)																	
7		Upper Left		Upper Right		Lower Left		Lower Right											
8		x	y	x	y	x	y	x	y										
9		0	0	639	0.00	0	481	639	481										
10																			
11		Marker Locations Using IPPLUS (Pixels)									Marker Locations wrt Origin (Pixels)								
12		Marker #1		Marker #2		Marker #3		Marker #4			Marker #1		Marker #2		Marker #3		Marker #4		
13		x	y	x	y	x	y	x	y		x	y	x	y	x	y	x	y	
14		99	106	108	272.00	163	219	215	139		0	0	9	166	64	113	116	33	
15																			
16		Marker #5		Marker #6		Marker #7		Marker #8			Marker #5		Marker #6		Marker #7		Marker #8		
17		x	y	x	y	x	y	x	y		x	y	x	y	x	y	x	y	
18		287	163	309	221.00	371	204	383	127		188	57	210	115	272	98	284	21	
19																			
20		Four Corners of Image (in)								Percent error	0	100	166.2438	72.93132084	129.87	72.96662361	120.6026534	72.6649137	
21		Upper Left		Upper Right		Lower Left		Lower Right			196.45	72.91433	239.4264	73.40746148	289.12	73.47341116	284.7753501	73.2700244	
22		x	y	x	y	x	y	x	y		0		45		35.107		32.9668394		
23		0	0	163.1489	0.00	0	122.808511	163.14894	122.8085106		53.21		63.66956		76.693		76.12038163		
24																			
25		Marker Locations wrt Origin (in)									Marker Locations Using Tape Measurer (in)								
26		Marker #1		Marker #2		Marker #3		Marker #4			Marker #1		Marker #2		Marker #3		Marker #4		
27		x	y	x	y	x	y	x	y		x	y	x	y	x	y	x	y	
28		0	0	2.297872	42.38	16.3404	28.8510638	29.617021	8.425531915		0	0	0	45	15.5	31.5	31.25	10.5	
29																			
30		Marker #5		Marker #6		Marker #7		Marker #8			Marker #5		Marker #6		Marker #7		Marker #8		
31		x	y	x	y	x	y	x	y		x	y	x	y	x	y	x	y	
32		48	14.553191	53.61702	29.36	69.4468	25.0212766	72.510638	5.361702128		50.25	17.5	54.75	32.5	71.3	28.25	75.75	7.5	
33																			
34																			
35		Pendulum	mass(g)	length(in)															
36			100	51.25															
37																			
38		Pendulum (Pixels)					Pendulum wrt Neutral (Pixels)					Pendulum wrt Origin (in)							
39		Image	x	y	Time (sec)		Image	x	y			Image	x	y	c	cos theta	theta	theta degrees	
40		Neutral	310	221	0.00														
41		1	158	212	0.00		1	-152	-9			1	-36.0688	-2.13565355	36.132	0.767618286	0.69567965	39.8797252	
42		2	258	216	0.47		2	-52	-5			2	-12.3393	-1.186474194	12.396	0.972647414	0.234427802	13.4385364	-1.6
43		3	445	186	0.94		3	135	-35			3	32.0348	-8.305319359	33.094	0.805053943	0.635029929	36.4029896	-4.3
44		4	442	186	1.41		4	132	-35			4	31.32292	-8.305319359	32.405	0.813082313	0.621368904	35.6198735	-4.2
45		5	260	216	1.88		5	-50	-5			5	-11.8647	-1.186474194	11.924	0.974692093	0.225456789	12.9242745	-1.6
46		6	157	175	2.35		6	-153	-46			6	-36.3061	-10.91556259	37.912	0.744164622	0.731512932	41.9338623	-4.8
47		7	254	216	2.82		7	-56	-5			7	-13.2885	-1.186474194	13.341	0.968317507	0.252393413	14.4684122	-1.8
48		8	435	192	3.29		8	125	-29			8	29.66185	-6.881550326	30.45	0.834962377	0.582731913	33.4050141	-4.0
49		9	439	189	3.76		9	129	-32			9	30.61103	-7.593434843	31.539	0.822944879	0.604221061	34.6368761	-4.1
50		10	293	220	4.23		10	-17	-1			10	-4.03401	-0.237294839	4.041	0.997093349	0.07626349	4.37179239	-0
51		11	165	182	4.70		11	-145	-39			11	-34.4078	-9.254498715	35.631	0.774022941	0.685625844	39.3033923	-4.6
52		12	229	209	5.17		12	-81	-12			12	-19.2209	-2.847538066	19.431	0.932796231	0.368701185	21.1357367	-2.6
53		13	410	202	5.64		13	100	-19			13	23.72948	-4.508601938	24.154	0.896152386	0.459774949	26.3565257	-3.2
54		14	449	184	6.11		14	139	-37			14	32.98398	-8.779909037	34.133	0.792625505	0.655693139	37.5875048	-4.4
55		15	260	216	6.58		15	-50	-5			15	-11.8647	-1.186474194	11.924	0.974692093	0.225456789	12.9242745	-1.6
56																			
57		Disk	mass	radius	center to marker														
58			450 g	2.25 in	2 in														
59																			
60																			
61		Rolling Disk Center (Pixels)					Rolling Disk Center wrt Neutral (Pixels)					Rolling Disk Center wrt Neutral (in)							
62		Image	x	y	Time (sec)		Image	x	y			Image	x	y		linear velocity	linear acceleration		
63		Neutral	443	417	0.00														
64		1	442	418	0.17		1	-1	1			1	-0.24145	0.241448692		13.11846539	54.25357968	4.76449352	
65		2	433	419	0.33		2	-10	2			2	-2.41449	0.482897384		22.16072867	60.03274328	-0.5797214	
66		3	418	422	0.50		3	-25	5			3	-6.03622	1.207243461		32.16618588	22.03487226	0.21090879	
67		4	396	425	0.67		4	-47	8			4	-11.3481	1.931589537		35.83866459	81.53001625	7.40880064	
68		5	372	431	0.83		5	-71	14			5	-17.1429	3.38028169		49.42700063	13.42931177	3.8072869	
69		6	345	435	0.97		6	-98	18			6	-23.662	4.346076459		47.63642573	53.73864792	3.65552682	
70		7	332	437	1.03		7	-111	20			7	-26.8008	4.828973843		51.21900226	116.0774532	6.61261265	
71		8	318	439	1.10		8	-125	22			8	-30.1811	5.311871227		58.95749914	436.3791797	7.81116498	
72		9	302	442	1.17		9	-141	25			9	-34.0443	6.036217304		29.86555383	2011.733298	-0.9053101	
73		10	294	444	1.23		10	-149	27			10	-35.9759	6.519114688		-104.2499994	84.52702653	-7.1573073	
74								-443	-417				-106.962	-100.6841046					
75																			
76		Rolling Disk Edge (Pixels)					Rolling Disk Edge wrt Neutral (Pixels)					Rolling Disk Edge wrt Neutral (in)							
77		Image	x	y	Time (sec)		Image	x	y			Image	x	y	c	cos theta	theta (rad)	theta (deg)	ang
78		Neutral	443	406	0.00														
79		1	435	408	0.17		1	-8	2			1	-1.93159	0.482897384	1.7073	0.712111255	0.778295486	44.6156648	6.84
80		2	420	416	0.33		2	-23	10			2	-5.55332	2.414486922	3.6856	-0.341561554	1.919374199	110.02782	5.25
81		3	409	427	0.50		3	-34	21			3	-8.20926	5.070422535	4.4324	-0.940370144	2.79451317	160.195022	-0