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Accuracy and precision of an external-marker tracking-system for radiotherapy treatments

[1]E M DONOVAN, PhD, [2]P BRABANTS, [1]P M EVANS, DPhil, [1]J R N SYMONDS-TAYLER, MSc and [3]R WILKS, PhD

[1]*Joint Department of Physics, Institute of Cancer Research and Royal Marsden Foundation Trust, Downs Road, Sutton, Surrey SM2 5PT,* [2]*QADOS Ltd, 5 Lakeside Business Park, Swan Lane, Sandhurst, Berkshire GU47 9DN and* [3]*Osiris Systems Ltd, Burraton Bungalow, Broadclyst, Exeter, Devon EX5 3DB, UK*

ABSTRACT. The purpose of this work was to determine the accuracy and precision of a real-time motion-tracking system (Osiris+) for the monitoring of external markers used on patients receiving radiotherapy treatments. Random and systematic errors in the system were evaluated for linear (1D), circular (2D) and elliptical (3D) continuous motions, and for a set of static positions offset from an origin. A Wellhofer beam data measurement system and a computer controlled platform (which could be programmed to give motion in 3D) were used to move a hemi-spherical test object. The test object had four markers of the type used on patients. Three markers were aligned in the central plane and a fourth was positioned out of plane. Errors were expressed as deviations from the planned positions at the sampled time points. The marked points on the test object were tracked for the linear motion case with a variation from the true position of less than ± 1 mm, except for two extreme situations. The variation was within ± 2 mm when the lights were dimmed and when the amplitude of the movement was ± 5.0 cm. The 2D circular motion was tracked with a standard deviation of 1 mm or less over four cycles. The sampling rates of the system were found to be 0.3–0.4 s when it was monitoring actively and 1.5–1.6 s otherwise. The recorded Osiris+ measurements of known static positions were within ± 1 mm of the value from the computer controlled platform moving the test object. The elliptical motions in 3D were tracked to ± 1 mm in two directions (*Y*,*Z*), and generally to within ± 2 mm for the third direction (*X*); however, specific marked points could display an error of up to 5 mm at certain positions in *X*. The overall displacement error for the 3D motion was ± 1 mm with a standard deviation of 2.5 mm. The system performance is satisfactory for use in tracking external marker motion during radiotherapy treatments.

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Portal imaging protocols for treatment verification and data analysis have been derived, and used to determine random and systematic errors in patient set up, based on bony anatomy and internal markers for a range of treatment sites, for example, breast [1, 2], prostate [3–5] and lung [6]. The data thus measured has been used to determine appropriate margins around organs at risk for radiotherapy planning [7–9]. This type of protocol is well-established and interest has moved towards real time monitoring of both external and internal organ movement.

Information about external motion throughout the duration of the treatment may be used in combination with electronic imaging of internal structures to improve further the accuracy and precision of radiotherapy treatment. This may be of particular value in situations where the radiation delivery is gated to a physiological function such as breathing [10–12], or where there is potential for the treated organ to be mobile, an example being the breast.

There is considerable interest in respiratory gating for thoracic tumours treated with radiotherapy. The clinical problem is significant as the large margins necessary to create a planning target volume (typically 1.5 cm) limit the prescribed dose to the tumour so that normal tissue tolerances are not exceeded. If these margins could be reduced by some control of the tumour motion, it might be possible to escalate the dose to the tumour [13, 14]. Systems which have been used to investigate thoracic tumour motion and respiratory gating include those based on external devices [15] and internal markers [16]. Some authors have evaluated the correlation of the signals from devices placed on the abdomen and thorax with tumour motion monitored with kilovoltage imaging [17, 18]. Others have explored the variation of internal markers in the tumour with imaging [19]. It appears from these studies that it is difficult to generalize on any relationship between external and internal motion and that this needs to be determined on an individual patient basis [16]. One component of any system required to investigate this is a means of tracking external markers, either to correlate to internal motion, or to provide a signal for gating of the linac.

We have investigated the tracking capability of a system called Osiris+ (QADOS, Sandhurst, Berkshire)

[20]. The Osiris+ equipment is a simple camera-based system which enables the user to check patient contours at the time of treatment and to monitor skin marks. Patients are positioned for treatment using skin tattoos, often highlighted by external, cross-shaped pen markers on their skin. The system has a function to monitor such marks. This function can be used to ensure that the patient has not moved during the radiation delivery and has the potential to provide a signal to be used in gating. It does not require any monitoring equipment to be fixed to the patient. It is one of a number of systems which provide a motion tracking function [15, 21, 22]. The measurement errors of any tracking system must be evaluated prior to any potential use in monitoring movement. For any tracking system to fulfil its purpose, the system measurement errors must be much lower than the movement to be measured. The purpose of this work was to determine the accuracy and precision of the Osiris+ system when tracking markers.

Methods and materials

Osiris+ system

The Osiris+ equipment may be installed in radiotherapy simulator and treatment rooms without modifications to the simulator or treatment equipment, or direct patient contact [20]. It consists of a set of wall mounted cameras which are used with the in-room alignment lasers to acquire patient contours at multiple levels along the patient, or alone, to track markers on the patient's skin. When the system is used for acquiring external outlines, images of the patient in the set-up position are captured and the patient outline and the reference marks may be generated by means of an automatic outlining function. The Osiris+ system also has a real time movement monitoring function which allows skin marks to be tracked during irradiation using stereoscopy – the mathematical combination of two images taken using different camera positions to create three-dimensional information. The real time movement monitoring uses the marks present on the patient's skin, or immobilization shell, and does not require any external markers to be adhered to the patient. Our evaluation of the system concentrated on this monitoring function.

The system was installed in a linac treatment room. It had four cameras mounted on the walls, all along a line of sight to the linac isocentre. The user indicates the points to be tracked on still images of the target object. Each point must be seen by two cameras in order to be tracked in 3D. After the points have been selected, the system displays real time images from the camera acquired at a slow frame rate. The active motion tracking is initiated manually and the system acquires images at a faster frame rate for the duration of the tracking period. This is referred to as the ''linac on'' state in the software although the acquisition of motion data does not currently gate to the linac pulse production. The tracking time is determined by the user. A point tracking algorithm determines the coordinates of the selected points in space and time and stores these in a simple spreadsheet format. The image acquisition rates and the accuracy and precision of the system were all evaluated in the experiments described.

Description of point tracking algorithm

A pattern matching function has been implemented in the Osiris+ system to enable the tracking of points. The function is a grey level and colour pattern matching library. The system is trained on a reference pattern and afterwards locates its occurrences in other images. The library works by superimposing the pattern over the image and comparing them by computing a (normalized) correlation score, *i.e.* measuring discrepancies between the pattern and the target image.

For each point selected, a search region of interest 100 pixels square is defined, and a central region of interest of 15 pixels square is stored as a search pattern. When locking on points, a match is searched for only in the search region. This typically allows about ± 40 mm of search area – depending upon the calibration values for that camera. (If the whole image were searched for a match, the process would take too long, especially if several points are being tracked).

If all positions had to be tried for a match, this would lead to an unacceptable running time. To alleviate this, a coarse-to-fine approach is used. This means that several search stages called reductions are performed. At the coarsest reduction, an approximate location is found quickly. Then the location is improved, using the next reductions, and working in a close neighbourhood. This arrangement drastically reduces the number of positions to be tried. At the final stage, additional processing can be done to achieve sub-pixel accuracy.

Points are not ''lost'' if they are temporarily obscured, but the data associated with those points when obscured or out of range will be set to a null.

Point matching enables a point selected from the image obtained from a camera to be ''found'' whenever the image is updated. The location of each point found is indicated by its x, y screen coordinates. For this location to be translated from ''screen coordinates'' (pixels) to a position in space (world coordinates – mm) it is necessary for the same point to be seen by at least two cameras. Osiris+ uses an x, y, z world coordinate system where x is lateral, y is vertical and z is longitudinal. The centre of each camera's field of view is the isocentre of the machine. At the isocentre ''z'' is always considered to be 0, *i.e.* ''Z_0''. ''X'' and ''Y'' coordinates are considered to be in this Z_0 plane.

The calibration of the Osiris+ system results in the position of each camera being known relative to the isocentre and so, any x, y screen coordinate of a point lying in the Z_0 plane seen by any one camera can mathematically be translated to its true world coordinates, X, Y mm in the Z_0 plane only. However, if the same point is seen by another camera then it is possible to translate the screen coordinates for that point (*e.g.* x_1, y_1 for camera 1 and x_2, y_2 for camera 2) to world coordinates of X,Y and particularly, Z mm.

The solution is to solve for vector or ''skew'' lines, which are lines in space that are not parallel. If the same points can be seen by camera 1 and camera 2, then for each point selected from camera 1 it is necessary to correlate that point with one of the points selected from camera 2. This is done by generating a skew line which passes through x_1, y_1 between $Z=0$ and $Z=100$ (camera 1). For each point from camera 2, skew lines are similarly generated and the one which passes closest to that from camera 1 (<5 mm) is considered to be derived from the same point, say, x_2, y_2 on camera 2. These two points are then correlated. The process is repeated for all points selected from camera 1 against all points selected from camera 2, ignoring those already correlated. It is then possible using direction cosines to determine the X, Y and Z coordinates for each pair of correlated points.

The correlation process described occurs only once when the points to be tracked are defined. After that, every time a fresh set of images is acquired, a pattern match is attempted for each point from each camera. This matched point will have screen coordinates of x_1', y_1' etc., which may or may not be the same as the last time around. The actual position/movement of the point can then be determined in world coordinates. The repetition rate is dependant upon how many points are being tracked and how long it takes to find a match.

Determination of accuracy and precision

A rigid hemi-spherical test object was used to evaluate the Osiris+ system in all of the experiments. The test object was marked, using a permanent ink pen, with three markers in the central plane and one out of plane marker, as shown in Figure 1. The markers were cross shaped of 1.5 cm length and 0.2 cm width.

The Osiris+ system was used to track continuously throughout each movement set. Each mark on the test object was seen by at least two cameras and was manually indicated by the user on a static camera image. For the marker on the top of the test object, there was a systematic discrepancy in the position indicated by the user on the two camera views of 2 mm. The system recorded and tracked all marked positions separately, hence the data are recorded for five points where points 3 and 4 refer to the same marker.

Once the positions are marked by the user, the system begins monitoring at a slow frame rate. Active monitoring at a faster frame rate is initiated by the user (this corresponds to the ''linac on'' state). In all experiments the active mode of Osiris+ was activated prior to the movements driven by two motorized systems. The output from the Osiris+ system uses a binary tag to indicate whether passive or active monitoring is being recorded. The active monitoring state is referred to as ''linac on'' in the system software. It is initiated manually rather than being gated to the linac pulse production. All experiments were performed without radiation.

The two motorized systems used were a clinical beam data measuring system and an experimental programmable platform. The advantage of the clinical system was that its measurement integrity had been well validated. However, it was difficult to use this system to create more complex motions in 3D. The programmable platform allowed the input of any function and hence provided additional flexibility.

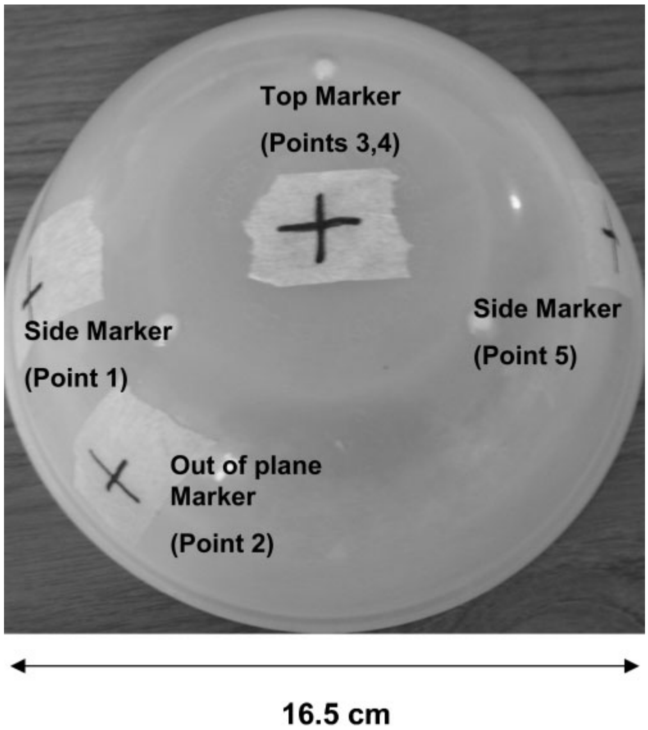

Figure 1. Photograph of the test object with markers. The photograph is taken from above the test object. The height of the object is 8.0 cm. There are three markers in a plane and one out-of-plane marker. One camera pair viewed the left-side, top and out-of-plane marker; a second camera pair viewed the top and right-side markers.

Using Wellhofer beam measurement system

A Wellhofer beam measurement system (Wellhofer Scanditronix, Schwartzenbruck, Nurnberg, Germany) was used for the first set of experiments. This system was in routine clinical use and the positional accuracy of the detector carriage had been verified previously to be 0.1 mm. The test object was fitted into the detector holder of the system and hence could be moved around in 3D space. It was aligned with the sagittal and lateral room set up lasers using the three central plane markers, and that position was defined as the origin. The Wellhofer system was used to drive the test object in each of the three cardinal directions from the origin at the amplitudes and speeds given in Table 1 in a linear movement that was repeated five times. The Linear 1 conditions were taken as the reference conditions and one parameter was changed to give each of the linear movement conditions labelled 2 to 7.

The coordinate system of the Wellhofer equipment was related to the Osiris+ and Elekta linac treatment room coordinate system in the following way: Z=Gun−Target (GT) (longitudinal) direction, Y=vertical, X=transverse (lateral) direction. The Osiris+ system is designed to be used with maximum room illumination; one of the tests was carried out with dimmed lighting to test the ability of the system to track marks under more extreme conditions.

A further experiment moved the phantom in the Z–Y (GT/vertical) plane in an approximation to a circle. The coordinates of movement are shown in Figure 2 and the

Table 1. Summary of the experimental parameters for the linear motion using the Wellhofer beam data measurement system

Experiment number	Direction	Speed (mm s^{-1})	Amplitude (cm)	Number of points tracked	Room light conditions
Linear 1	Z (GT)	10.5	$\pm$1.0	5	On
Linear 2	Z (GT)	10.5	$\pm$1.0	5	Off
Linear 3	Z (GT)	10.5	$\pm$1.0	3	On
Linear 4	Z (GT)	0.87	$\pm$1.0	5	On
Linear 5	Z (GT)	10.5	$\pm$5.0	5	On
Linear 6	X (Lateral)	10.5	$\pm$1.0	5	On
Linear 7	Y (Vertical)	10.5	$\pm$1.0	5	On

GT, gun–target axis of the linear accelerator.

Wellhofer system was programmed to drive between the positions in a straight line at a speed of 10.5 mm s^{-1} with no pause between sections. This sequence of movements was repeated four times.

Using programmable computer controlled platform with motion in X,Y,Z

The computer-controlled platform (Time and Precision, Basingstoke, UK) has three orthogonal axes driven by leadscrews and stepper motors. Each axis has an incremental encoder which allows the position to be known at a resolution of 0.5 µm, even if a motor skips steps. The motors are microstepped to give a drive resolution of 0.5 µm. A versatile three-axis motion controller (Model DMC-2130; Galil Motion Control, Rocklin, CA) generates the step and direction signals to the three motor drives, according to the specified trajectory. The controller also keeps track of the actual position of the axes via the encoders, but the steppers are run open-loop. The difference between commanded position and actual position is less than 0.02 mm.

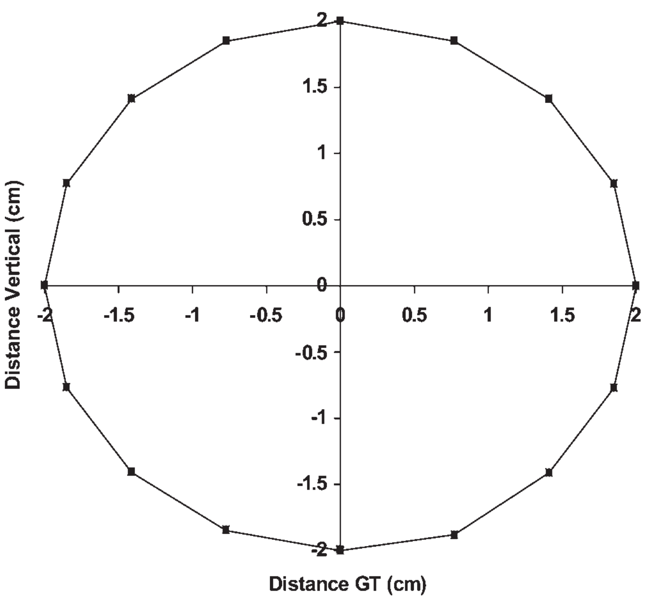

Figure 2. Coordinates of circular motion in *Y–Z* plane (Vertical: gun–target (GT) plane) using the Wellhofer beam data system.

The test object was fixed on the platform and aligned to the room lasers using the three markers in the central plane to define the origin position. The platform was used to drive the test object to 3 points in *X,Y,Z* from this origin: $\pm$1 cm, $\pm$2 cm, $\pm$4 cm. After each set of movements in the three cardinal directions, the test object was returned to the origin. This experiment was designed to assess the absolute positional accuracy of the system. The platform was used to drive the test object in four elliptical trajectories in three-dimensional space. To generate the ellipses, the controller was run in its ''electronic cam'' mode, in which the trajectories of the three axes are cyclically synchronised to a virtual cam axis. Commands were sent to the controller from a laptop via a serial link. These trajectories corresponded to an ellipse of eccentricity 0.6 tilted at 45° in both horizontal and vertical planes. The details are listed in Table 2.

Results

Using the Wellhofer beam measurement system

Linear motion: positional data

These data were analysed by evaluating the difference between the true position and time, as given by the speed and period of the Wellhofer equipment, with that recorded by the Osiris+ system. Figure 3 provides a summary of the standard deviation of the positional data difference for the seven experiments. For each experiment the data are separated into the *X,Y,Z* components of movement and are presented as the average over all of the tracked points and over all five cycles. Each of these experiments involved motion in one of the cardinal directions only. The direction of motion of the test object is indicated by the black bar on the chart. Data were collected for all three directions. The largest standard deviations are found for experiment 2, when the system was tracking the points under dimmed lighting, and for experiment 5 where the motion had a large amplitude of $\pm$5.0 cm. Neither of these two conditions resulted in standard deviations of greater than 2 mm; the other experiments showed that the system could track the points with standard deviations of less than 1 mm. The conditions in which the system tracked the motion with the greatest precision were when the motion was slow (0.87 mm s^{-1}) and here the standard deviations did not exceed 0.4 mm. Table 3 shows the standard deviation

Table 2. Summary of elliptical motion tracking experiment parameters carried out using the computer controlled platform to drive the test object

Experiment number	Eccentricity	Semi-major axis amplitude (cm)	Period (s)
Ellipse 1	0.6	2.0	6
Ellipse 2	0.6	1.0	2
Ellipse 3	0.6	1.0	4
Ellipse 4 (circle)	1.0	1.0	4

data averaged over all directions and for all points for all the experimental conditions.

Circular motion: positional data

The data of Figure 4 show the standard deviation for the 2D circular motion in the Y–Z plane (GT, vertical) for each of the repeat cycles. The data are given for each tracked point averaged over the Y and Z positions recorded by the Osiris+. The standard deviation values were determined from the difference between the recorded values at each Osiris+ monitoring time point and the expected Y, Z values interpolated from the Wellhofer driven movements between points. The standard deviation does not exceed 1 mm and the average value over all cycles and points is 0.66 mm. Values of the X coordinate were recorded also, although the movement was not in this direction. The average value of one standard deviation over all cycles and points is 0.5 mm.

Temporal data: linear and circular motion

The data from both linear and circular movements of the test objects have been used to determine the sampling rates of the Osiris+ system. Figure 5 shows that these are 0.3–0.4 s whilst the system is monitoring actively (*i.e.* ''linac on'' state) and 1.5–1.6 s in the ''linac off'' state.

Using the programmable computer controlled platform with motion in X,Y,Z

Stationary point measurement

Figure 6 summarizes the results obtained from the Osiris+ system when the test object was driven to specific, known displacements from its origin using the computer controlled platform. The Osiris+ system was assessed by determining the deviation of the recorded values from the absolute position coordinates, as given by the platform. Figure 6 gives the absolute differences in millimetres between the platform values and the recorded data from Osiris+. All the differences were within ± 1 mm. The test object was returned to the origin between each set of measurements and no variation in this recorded value was found throughout the experiment.

Table 3. SD (mm) averaged over all tracked points and each direction of motion for each of the linear motions of the test object driven by the Wellhofer beam data system

Experiment number	SD (mm)
Linear 1	0.64
Linear 2	1.43
Linear 3	0.55
Linear 4	0.33
Linear 5	1.14
Linear 6	0.49
Linear 7	0.42

Elliptical motion in 3D

Data from the analysis of elliptical movements 1 and 3 are used as an example of the ability of the Osiris+ system to track motion in 3D. The results for the ellipse experiments 2 and 4 follow the same pattern; as these add no further information, the data are not given. As an example, Figure 7 shows the movement in the X direction (transverse) for ellipse 1. The true, calculated trajectory and the trajectories recorded by the Osiris+ system are shown for each of the five points. The absolute difference between the exact positions on the elliptical trajectories and the recorded positions were determined for each point for each of the X,Y,Z directions. These data are given in Figure 8 for ellipse 1. Figure 8b,c shows that the absolute errors in Y and Z are within ± 1 mm for the majority of the positions, but the data in Figure 8a show that for points 1,2 and 3 the absolute error values are only within ± 4 mm for ellipse motion 1 in the X direction.

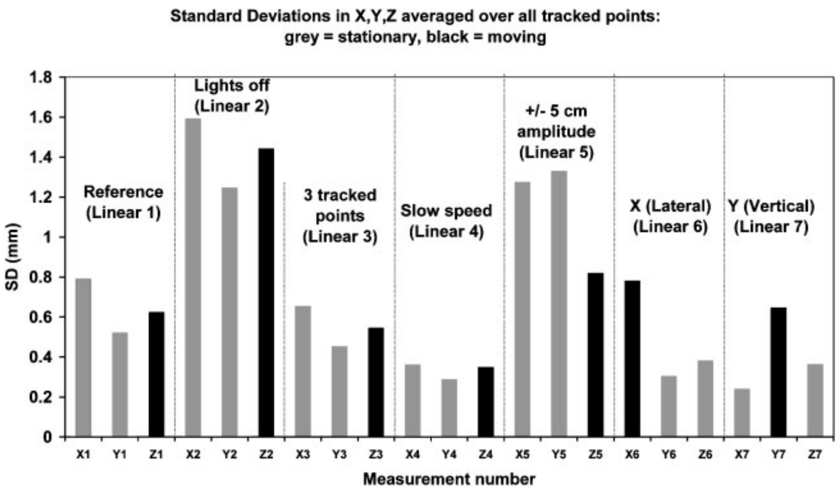

Figure 3. Summary of errors for linear motion. The plot shows the deviation from the exact to tracked position averaged over all five cycles of the linear movement.

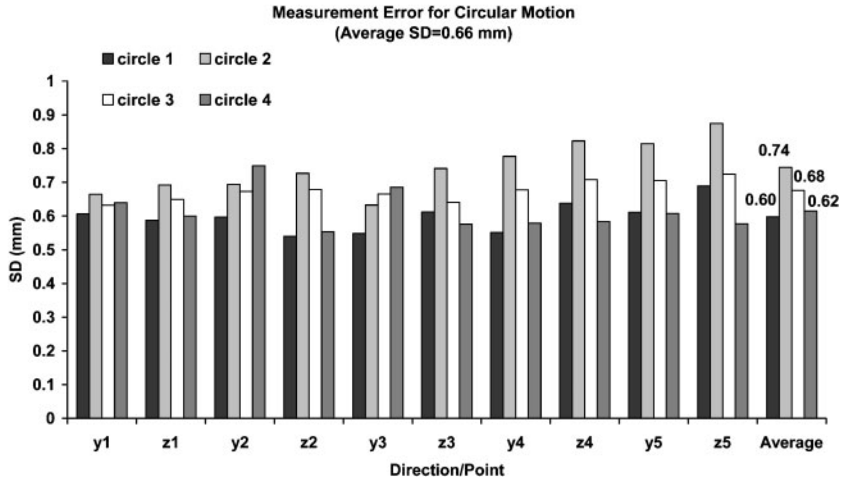

Figure 4. Summary of errors for circular motion. The values for each point are the average of the deviations from the calculated to tracked position.

Table 4 summarizes four parameters from the analysis of the elliptical movements 1 and 3. For each tracked point: the average displacement; the standard deviation of the variation and the minimum and maximum displacements are given. These are all averaged over the three cycles of the motion. The average value of the displacement is within ± 1 mm with an average standard deviation within 2.5 mm. The largest magnitudes of the minimum and maximum displacements are -4.72 mm and +4.0 mm, both for the ellipse 1 motion. In this experiment, the test object was moving at a fast speed and with the largest amplitude.

Discussion

The tracking of patient movement during a fraction of a radical radiotherapy treatment requires a monitoring system with sufficient accuracy and precision. One potential application of such a system is to use the signal as a trigger to gate a linac for delivery based on the respiratory cycle as described by Berson et al [10]. Real-time monitoring of patient movements also has an application in situations where control of breathing is used to reduce an organ at risk dose, as suggested by Lu et al [23] and reported by Remouchamps et al [24]. We have investigated the Osiris+ system in order to determine whether its performance characteristics were sufficient for this type of patient monitoring.

The systems used for respiratory controlled studies as described in the literature tend to be either of the Active Breathing Control (ABC) device [11] (now from Elekta Oncology Systems, Crawley, UK) or the Varian Medical Systems RPM^{TM} equipment (Varian Medical Systems, Palo Alto, CA) [10, 12]. These use a flow volume (the ABC device) or a marker on the patient's chest (Varian RPM) to monitor respiratory motion and breath-hold over time, in one dimension. The studies by Berson et al [10] and Pedersen et al [12] show that the trace of the external marker on a patient's chest has an amplitude of between 5 mm and 19 mm. It would be realistic to expect a monitoring system to detect movements of the external surface of a patient down to 2 mm.

Yan et al [22] examined the Novalis Body system (BrainLAB Inc., Germany) which uses a combination of infrared and X-ray imaging for tracking markers. In an experiment similar to the absolute position checking, they moved a phantom known distances (2 mm, 5 mm, 10 mm and 20 mm) and determined the positional error of the system in X, Y and Z. They quote the average errors in the lateral direction as 0.6 ± 0.3 mm; those in the vertical direction as 0.7 ± 0.2 mm and those in the longitudinal

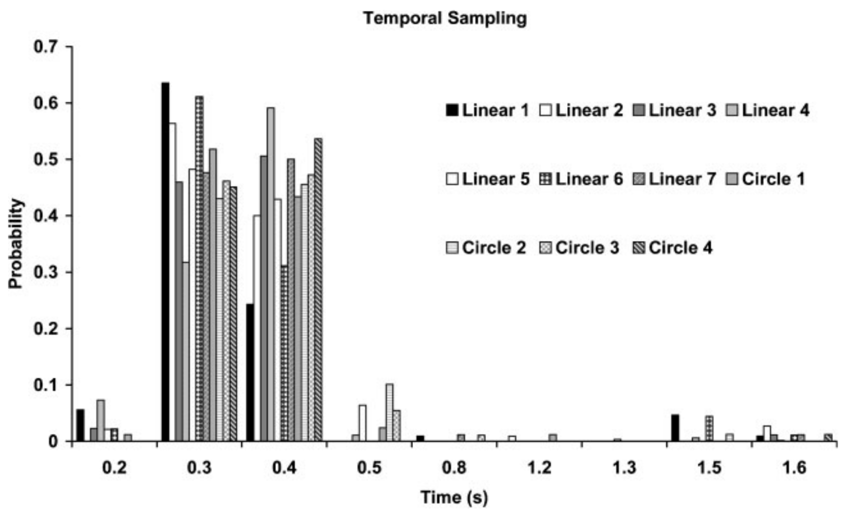

Figure 5. Summary of sampling intervals. Data are from linear and circular motion.

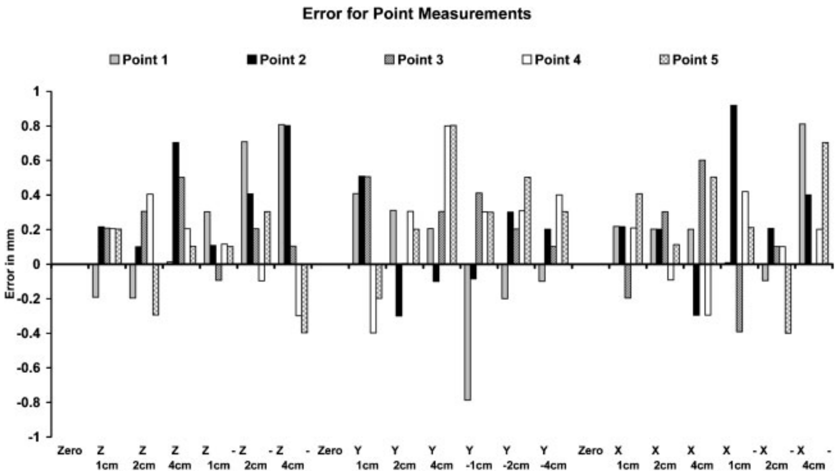

Figure 6. Summary of errors for all points at all positions for the test object moved using the programmable platform.

direction as 0.5 ± 0.2 mm. The results from the Osiris+ system given in Figure 6 compare well with these data.

Yan et al did not investigate the continuous tracking of markers on a moving object. Our assessment of the Osiris+ system covered a range of movements in one, two and three dimensions and different speeds. Figure 3 and 4 demonstrate that the errors in tracking for the sawtooth and 2D circular motions were within ± 1 mm for most conditions. Two situations, which were more extreme, were the linear 2 and 5 experiments. The former used the Osiris+ with the lights dimmed and the latter had a ± 5 cm amplitude, which is much larger than would be found in practice. Here the errors rose above 1.5 mm. Shirato et al [21] evaluated the performance of a Real-Time Tumour-Tracking system (EXL-20DP; Mitsubishi Electronics Co., Ltd., Tokyo, Japan) using a phantom moving in a circle over a range of speeds from 6 mm s^{-1} to 40 mm s^{-1}. They quote the accuracy of the system as better than 1.5 mm; a similar level of accuracy to the Osiris+.

The largest displacement errors were in the tracking of the points when the test object was driven in the elliptical movements 1 and 3, but only in the X direction (transverse) and only for three of the points. Here the error could reach ± 5 mm for ellipse 1 and ± 3 mm for ellipse 3 at the extremes of the travel. The marker at the top of the test object was seen by two different pairs of cameras and recorded twice as point 3 and point 4. Only the point 3 X direction errors were large for this marker. The reason is unclear and this is under further investigation. The differences in the phase of the data (shown in Figure 7) may indicate that the cameras were measuring at different time points as data points 1, 2 and 3 were recorded by one camera pair and the data from points 4, 5 were from the other camera pair. The mean

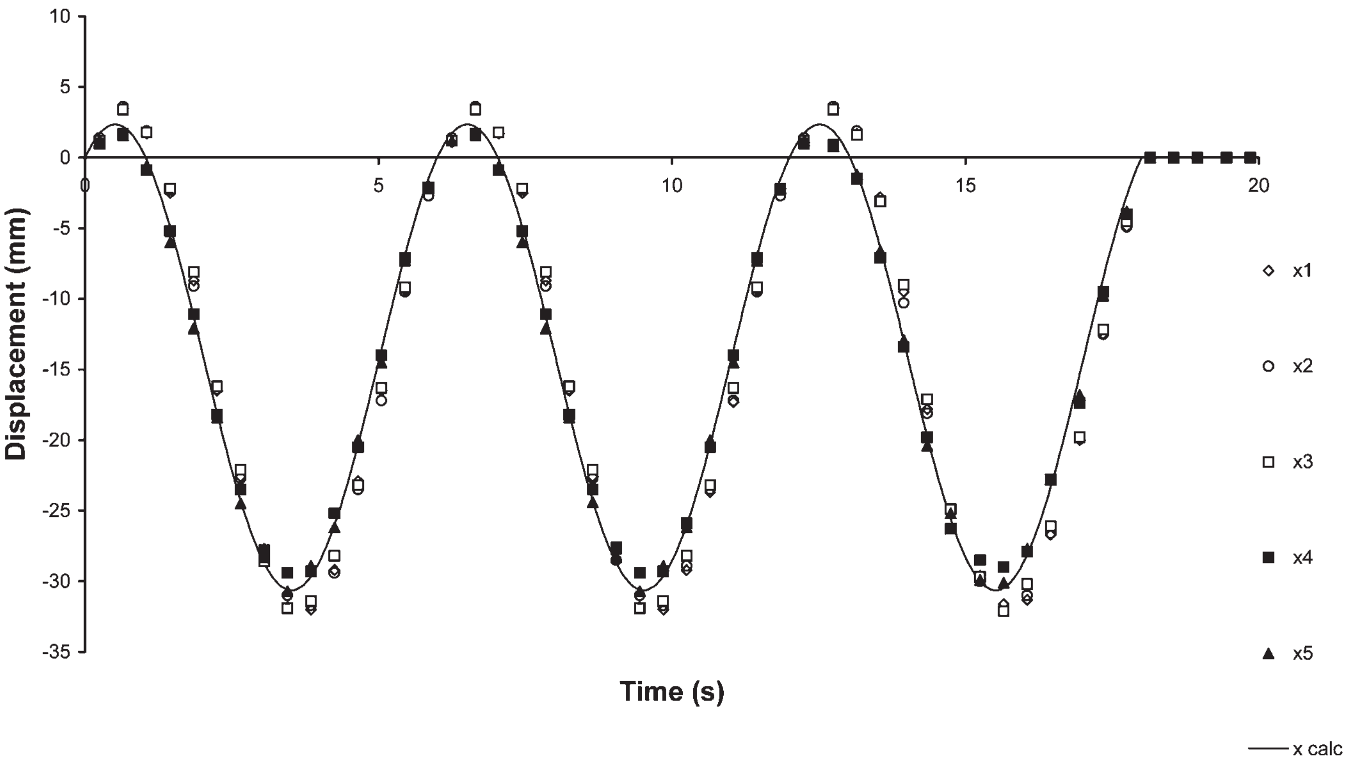

Figure 7. Data recorded from Osiris+ for displacement in X axis with time compared with programmed displacement for platform movement Ellipse 1.

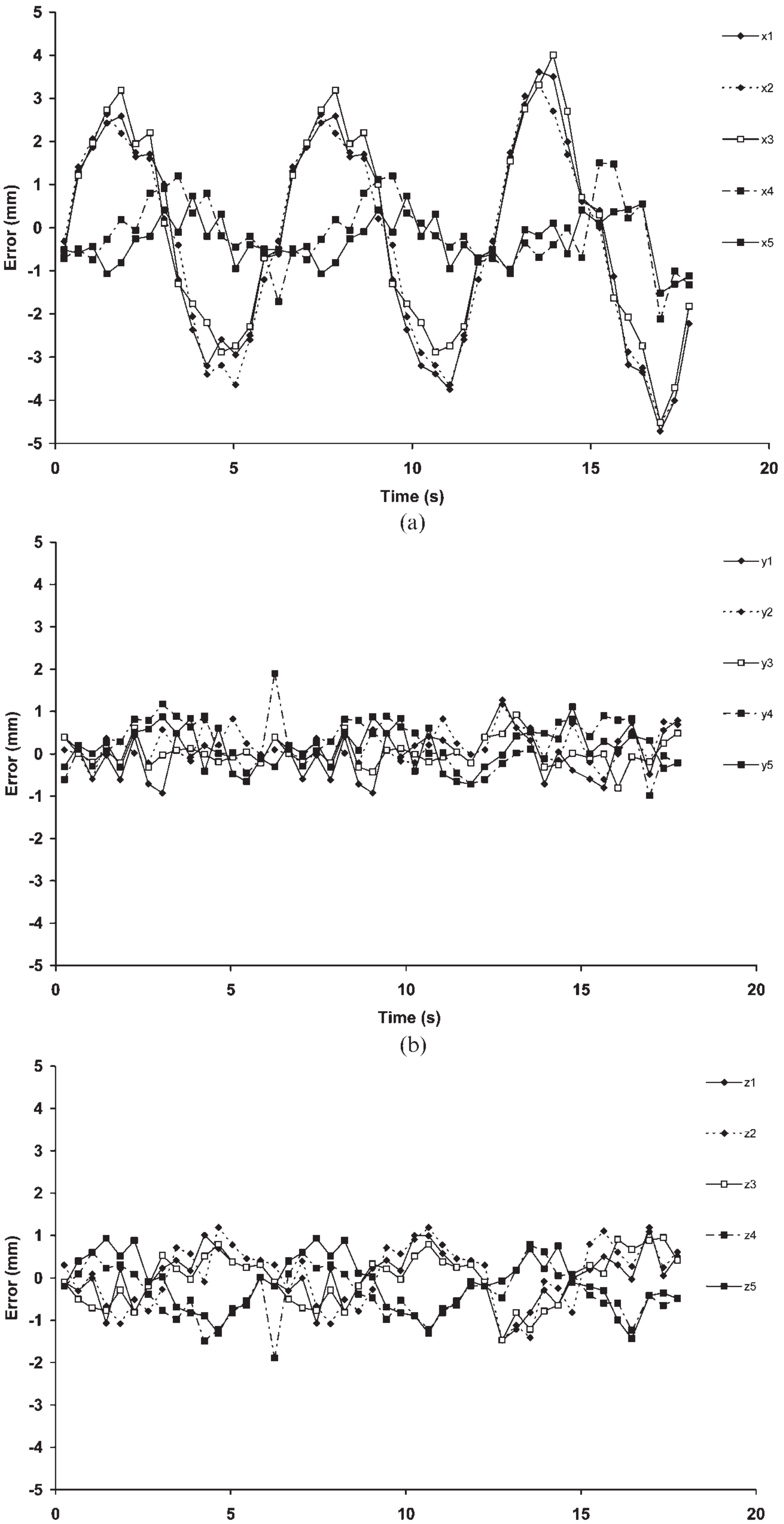

Figure 8. (a) Absolute error in position in the *X* direction for ellipse 1 for all points. (b) Absolute error in position in the *Y* direction for ellipse 1 for all points. (c) Absolute error in position in the *Z* direction for ellipse 1 for all points.

displacement error in the *X* direction was −0.23 mm ± 1.7 mm for Ellipse 1. The mean error in *Y* was 0.12 mm ±0.5 mm and that in the *Z* direction −0.09 mm ± 0.6 mm. For most situations investigated, the system performance was sufficient to meet the requirement to track movement with a minimum threshold of 2 mm and the imaging rate of one every 0.4 s was sufficient for good monitoring accuracy.

Table 4. Summary of error analysis data for elliptical movement 1 and 3 using the programmable platform

	Average (mm)		SD (mm)		Minimum (mm)		Maximum (mm)	
Ellipse number	1	3	1	3	1	3	1	3
Direction/point								
X1	−0.3	0.48	2.37	1.54	−4.72	−1.88	3.61	3.15
Y1	−0.01	−0.43	0.52	0.37	−0.93	−1.35	1.27	0.41
Z1	0.02	0.76	0.6	0.39	−1.47	−0.21	1.19	1.47
X2	−0.34	0.56	2.32	1.43	−4.52	−1.68	3.31	3.05
Y2	0.19	−0.58	0.39	0.35	−0.6	−1.19	1.17	0.21
Z2	0.06	0.45	0.73	0.51	−1.47	−0.81	1.19	1.37
X3	−0.07	0.7	2.28	1.6	−4.52	−1.98	4.0	3.38
Y3	0.03	−0.51	0.32	0.39	−0.81	−1.39	0.92	0.26
Z3	−0.04	0.54	0.6	0.41	−1.47	−0.45	0.95	1.47
X4	−0.12	0.56	0.81	0.69	−2.12	−0.54	1.5	2.03
Y4	0.26	−0.36	0.59	0.55	−0.99	−1.81	1.89	0.45
Z4	−0.35	0.51	0.6	0.57	−1.89	−0.52	0.78	1.65
X5	−0.31	0.39	0.56	0.62	−1.52	−0.45	0.74	1.83
Y5	0.14	−0.54	0.47	0.45	−0.72	−1.81	1.11	0.44
Z5	−0.15	0.43	0.65	0.62	−1.43	−0.72	0.93	1.75

The errors are derived from the difference between the calculated position from the input function to the platform and that recorded by the Osiris+ tracking software at the sampled time points.

Conclusion

Assessment of the Osiris+ system found that continuous linear, circular and elliptical motions were tracked with a standard deviation of 1 mm in the difference between measured and true positions of the test object markers. Under more extreme conditions, such as dimmed lighting and large amplitude of motion, this increased to 2 mm. The recorded values of static, known displacements by the system were also within ± 1 mm. The sampling rates of the system were 1.4–1.5 s prior to the command to track and 0.3–0.4 s during the tracking time. It is recommended that the system be used with the lights on and that regular calibrations are carried out to maintain its performance.

The system performance is considered satisfactory to enable its use (i) in assessing external motion based on skin markers; (ii) in conjunction with electronic portal imaging to determine the nature, if any, of external-to-internal organ movement correlation and (iii) to provide a signal for respiratory gating.

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