# Experimental evaluation of kinect and inertial sensors for beating heart tracking

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***Abstract**:*

*This paper investigates the use of Kinect depth sensors as well as inertial sensors in the context of beating heart surgery. In the past, various sensors have been used in attempts to track the beating heart, each with its own distinct set of advantages and disadvantages. With the availability of affordable structured-light depth sensors such as the Kinect and sufficiently small and low priced inertial sensors, the question of their suitability for beating heart tracking arises. We performed in-vivo experiments on a porcine heart in order to assess the feasibility of beating heart tracking based on these sensors.*

*Keywords: depth camera, RGBD sensor, beating heart surgery, inertial measurement unit, arterial pressure*

## 1 Problem

Motion tracking of the beating heart is of interest for cardiac imaging and radiology. Precise information about the motion of the heart surface is particularly useful in the context of robotic surgery on the beating heart. In 2001, Nakamura et al. first introduced the idea of using a teleoperated robot that automatically compensates for the heart motion while presenting a stabilized view to the surgeon [1]. This allows the surgeon to perform surgery on the beating heart as though it were still. On-pump coronary bypass operation (OPCAB) on the beating heart has significant medical benefits compared to the ”on-pump” technique of cardioplegia with cardiopulmonary bypass (CPB) through a heart-lung machine. [2] CPB and the use of a heart-lung machine is always accompanied by heart injury caused by ischemia and the following reperfusion, but also bears the risk of severe immune reaction, anaemia, and cerebral microembolization by provoking clot formation. Additionally, beating heart surgery results in shorter hospital stays and is less expensive than heart surgery with CPB [3].

Different types of sensors have been used for beating heart tracking, for example regular cameras [4], [5] or endoscopes [6], [7], high-speed cameras [1], electrocardiography [8], pressure sensors [9], force sensors [10], and others. The availability of affordable RGBD (red, green, blue and depth) sensors with an accuracy in the range of 1 mm like the Microsoft Kinect poses the question of their suitability for beating heart tracking. To our knowledge, this is the first published work that uses a Kinect sensor for tracking the surface of the beating heart. As increasingly small and low priced inertial measurement units (IMUs) become available, their applicability to beating heart tracking is of interest as well. We are interested in capturing both the respiratory motion and the motion due to heartbeat with these sensors.

## 2 Methods

We performed an in-vivo experiment on a porcine beating heart (see Fig. 1a). From a median thoracotomy the anterior surface of the heart was approached, then a Microsoft Kinect for Windows sensor was positioned approximately 50 cm above the beating heart. Unlike the commonly used Xbox 360 Kinect sensor, which has a minimum measuring distance around 80 cm, a Kinect for Windows sensor can provide depth measurements down to a distance of roughly 40 cm. The size of the discretization step, i.e., the depth resolution, of the Kinect for Windows depends on the distance to the target and is 1 mm in the relevant range (see Fig. 2). Kinect data was recorded at a frequency of 30 Hz at a resolution of 640 x 480.

Two InvenSense MPU-9150 IMUs were used to evaluate the applicability of inertial sensors in the context of beating heart tracking. The size of an MPU-9150 is just 4 mm x 4 mm, which allows placing it on a small PCB with an area of approximately 1 cm x 1 cm (see Fig. 3). The first IMU was attached to the diaphragm in order to record the movement due to respiration, whereas the second IMU was attached to the pericardium in order to capture the motion due to heartbeat. The IMU data consisting of accelerometer and gyroscope measurements was recorded at a frequency of 135 Hz.

(a) A porcine heart with a Kinect mounted above.

(b) The camera system.

Figure 1: Experimental setup.

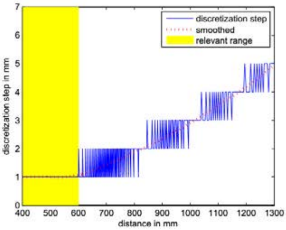


Figure 2: Discretization step size in relation to the distance to the target.

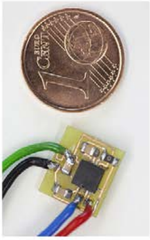


Figure 3: The inertial measurement unit used in the experiment.

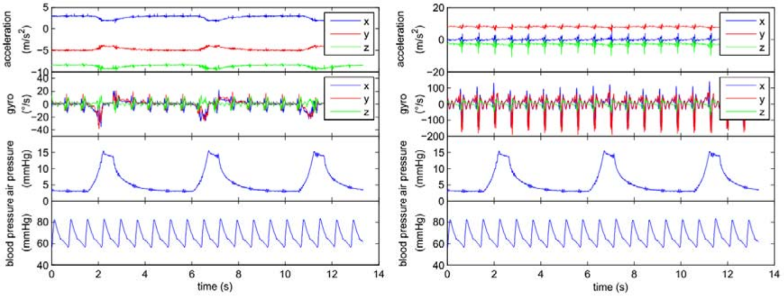
Furthermore, in order to compare the results to commonly used medical sensors, arterial blood pressure and air pressure inside the lung were recorded at a frequency of 1000 Hz. To obtain the actual movement of the heart surface, small markers were placed on the surface and captured with a PIKE F-210 color camera (see Fig. 4a). The marker positions were extracted by a color-based segmentation algorithm and their movement was tracked from frame to frame to obtain their trajectory in image coordinates. The experimental setup is depicted in Fig. 1a and Fig. 1b. Only one of the cameras visible in Fig. 1b was used in the discussed experiment.

## 3 Results

We recorded a sample of 80 s with all sensors mentioned above. For readability, we only show an excerpt of 14 s. Time stamps obtained by the different recordings were converted to the same format to plot data from the different sensors in a single graph. In the recorded depth images, the heart has a size of about 1000 to 2000 pixels and can thus be modeled as a point cloud with as many points. This is only a small fraction of the Kinect’s resolution of 307 200 pixels, but still significantly more than what can be obtained with commonly used approaches based on tracking landmarks using multi-camera systems.

For our evaluation of the Kinect data, we considered the average depth

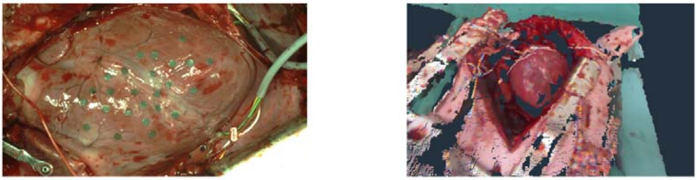
$$\bar{d} := \frac{1}{49} \sum_{u=-3}^{3} \sum_{v=-3}^{3} d(x+u, y+v)$$



(a) IMU at diaphragm.

(b) IMU at pericardium.

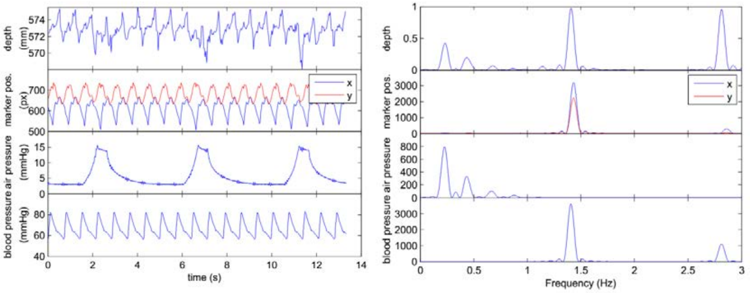
Figure 6: These plots show the signals obtained from the IMUs in comparison with the pressure sensors. Please note that the *x*-,*y*- and *z*-axis refer to the internal coordinate system of each sensor and are not identical to each other or the camera's coordinate system.



(a) The heart as seen by the conventional camera. Green markers have been placed on the heart surface.

(b) The three-dimensional point cloud produced by the Microsoft Kinect.

Figure 4: Example of data obtained from vision sensors.



(a) Recorded signals.

(b) Power spectral density.

Figure 5: These plots show the Kinect signals in comparison with the pressure sensors and the camera-based tracking. The respiration frequency is visible at 0.2 Hz and the heart frequency is visible at 1.4 Hz.

of the depth image $d(x, y)$ in a small area (7 x 7 pixels) around a point $(x, y)^T$. Since the heart movement is not restricted to the axis perpendicular to the RGBD sensor, this obviously does not represent the motion of a fixed point on the heart surface. Our results from the Kinect, the camera-based marker tracking, and the two pressure sensors are depicted in Fig. 5a. The depth information recorded by the Kinect camera clearly shows both respiratory motion and movement due to the beating heart. To further analyze the motion recorded by the Kinect sensor, we calculated the power spectral density of the different sensors (see Fig. 5b), where this is more evident because the frequencies of heartbeat (1.4 Hz) and respiration (0.2 Hz) clearly stand out. It is interesting to note that the breathing motion is very hard to detect in this experiment by tracking 2D marker positions since it occurs almost exclusively perpendicular to the image plane of the 2D camera. The Kinect's accuracy is obviously affected by the discretization interval of 1 mm, which is quite a significant limitation for this application. However, this is less apparent in our experiments because we average across a certain area. According to [7], an accuracy under 0.2 mm is required depending on the size of the vessels. In the future, new structured light cameras may provide smaller discretization intervals and thus allow more accurate tracking.

We directly compare the IMU data to the pressure recordings (Fig. 6). Not surprisingly, we find that the IMU at the diaphragm produces a signal with the same periodicity as the air pressure in the lung whereas the IMU at the pericardium produces a signal with the same periodicity as the arterial blood pressure. Each inhalation and each exhalation respectively as well as each heartbeat is clearly visible in the appropriate IMUs signals. These motions can be observed in both accelerometer as well as gyroscope data.

## 4 Discussion

Our results show the general suitability of depth sensors, such as the Microsoft Kinect, for tracking the surface of the beating heart. The Kinect is capable of following both heartbeat and breathing motion. While it is clearly possible to gain information about the movement of the heart in the Kinect data, the accuracy may be too limited to rely solely on the Kinect sensor for applications in the context of teleoperated beating heart surgery. A combination with more accurate sensors like a high-resolution multi camera system might be used to remedy this limitation. A fusion algorithm such as [11] may be employed to combine the advantages of both types of sensors.The data obtained from the IMUs looks promising as well. Even though it is hard to estimate absolute positions and orientations based on the IMU data, it is clearly possible to detect each heartbeat and inhalation as well as exhalation. Since IMUs can typically achieve a fairly high sampling rate, they may be a good addition to slower sensors like color or depth cameras.

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