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Design of Accurate Motion Capture System using Ultrasonic Communications
超音波通信を用いた高精度モーションキャプチャの設計

Tomohiko Sato[1†], Shigeki Nakamura[1], Kotaro Terabayashi[1], Masanori Sugimoto[1] and Hiromichi Hashizume[2] ([1]Univ. of Tokyo; [2]NII)
佐藤 智彦 [1†],中村 成希 [1],寺林 光太郎 [1],杉本 雅則 [1] ,橋爪 宏達 [2] ([1] 東大; [2] 国立情報学研究所)

1. Introduction

This paper proposes a new motion capture system based on ultrasonic communications. Compared to existing systems in the market using optical or magnetic sensing techniques, the proposed system can provide a highly cost-effective solution for entertainment or industrial applications. Furthermore, it can show sufficient advantages in accuracy over other low cost systems based on inertial sensors.

In our previous studies, we proposed an indoor localization system using the Extended Phase Accordance Method [1]. It could simultaneously and accurately identify not only the position but also the velocity of a moving object using a single compact receiver unit. This allows us to design an accurate motion capture system using ultrasonic communications only. In this paper, the principle of our motion detection technique and the design and implementation of our prototype system are described.

2. Motion Detection Method

The Extended Phase Accordance Method [1] proposed by the authors conducts accurate and simultaneous measurements of the distance between a receiver and a moving transmitter and its velocity. The transmitted ultrasonic signal, called a sync pattern, is a beat signal composed of two ultrasonic sine waves whose frequencies are different from each other, as shown in **Fig. 1**. Since the phases of the sine waves accord at only one time point, this point called an epoch is used as a reference point to determine the arrival time of a sync pattern. In current implementation, the sine wave frequencies are 39.75 kHz and 40.25 kHz, respectively.

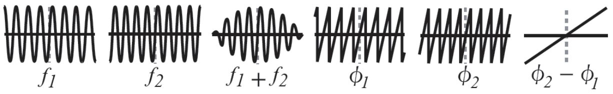
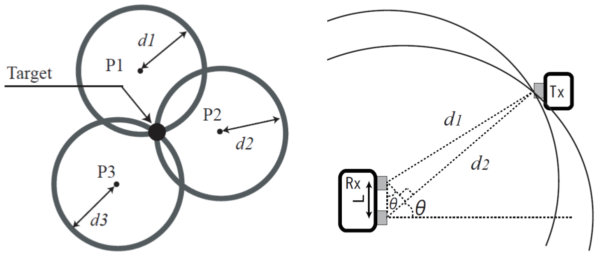


Fig. 1 A sync pattern and its epoch.



(a) Conventional method (P1,P2,P3:known positions to locate the target)

(b) Our method (Tx:ultrasonic transmitter Rx:ultrasonic receiver)

Fig. 2 Comparison of trilateration methods (in 2D).

For an accurate trilateration, multiple receivers are mutually placed apart to locate a transmitter target so as not to be affected by the distance measurement errors between the transmitter and the receivers as shown in **Fig. 2(a)**. On the other hand, the Extended Phase Accordance Method can measure the distance within 1 mm standard deviation in dynamic tracking environments. This standard deviation is less than 1/10 of the performances of the previously reported systems. Therefore, multiple sensors can be placed densely in a compact receiver unit as shown in **Fig. 2(b)**. In our current receiver unit, four sensors are placed to form a 76.2 mm square on a side. We use inexpensive ultrasonic transducers (about 600 JPY) for the implementation. More detailed descriptions on mathematical explanations of the algorithm and its implementations are given in our previous papers [1][2].

3. Proposed Ultrasonic Motion Capture System

The proposed ultrasonic motion capture system shown in **Fig. 3** is being implemented with our localization technique discussed in the previous section. Conventional systems using trilateration work only when three or more receivers are available in line-of-sight condition from a transmitter target. On the other hand, our system works even when a single receiver unit is available (**Fig. 4**). Therefore, our system can track transmitters attached to a human body more successfully than existing systems when the transmitters are occluded and cannot been seen from some receivers.

Each receiver observes a target velocity value as a projection of a spatial velocity vector of the moving

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tomo@itl.t.u-tokyo.ac.jp

target. Therefore, the placements of ultrasonic receivers have to be investigated for accurate velocity estimations. Considering the directivity (-45～45 degree) of the ultrasonic transducers used in our current system, the receiver units are placed to surround a target as shown in Fig. 3 so that each transmitter on the target in the tracking area faces to at least one receiver unit.

4. Experiments

We conducted motion tracking experiments in real environments. We moved the transmitter by using an electrical slider which moves at 0 ~ ± 1.5 m/s at the interval of 0.1 m/s and tracked straight line motions between 1.0 ~ 1.8 m.

Fig.5 shows the result of velocity and distance estimations in one dimension, and represents the estimation error as points and the standard deviations as error bars (±σ). From the result, it was proved that the proposed motion capture system showed very high performance in distance and velocity estimations. **Fig. 6** shows the motions of the transmitter tracked in three dimensions. As a result, the motions along a straight line were estimated with the standard deviations of approximately 38 mm and 0.1 m/s when the real velocity of the moving transmitter was ± 1.0 m/s. The deterioration of the standard deviation was due to the three dimensional localization by the trilateration with the very small baseline (76.2 mm). However, the obtained result was still comparable to other ultrasonic localization systems.

5. Conclusion and Future Work

In this paper, we proposed the design and implementation of our prototype ultrasonic motion capture system using the Extended Phase Accordance Method which enables to simultaneously estimate the position and the velocity of a moving object. The result of motion tracking experiments indicated the sufficient performance of our system.

There are several issues to be addressed. One important issue is to increase the update rate of the position and velocity estimations as much as possible. For this purpose, we are developing the estimation algorithm on FPGAs. We are also implementing a wireless time synchronization method between multiple transmitters and receivers and a position and velocity estimation filter algorithm for more precise motion capture.

References

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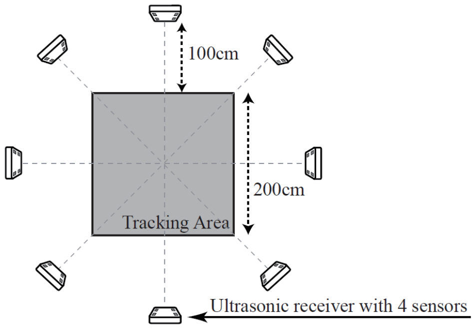
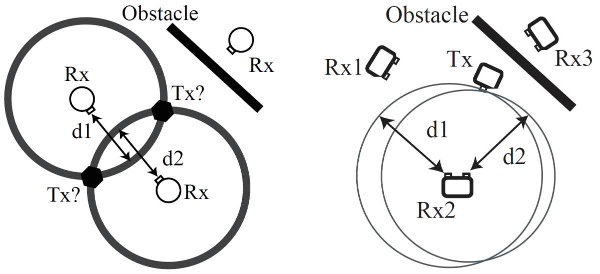
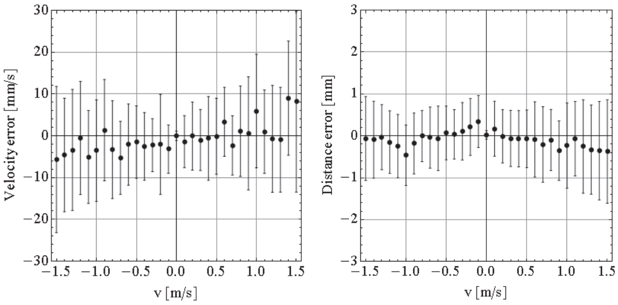


Fig. 3 Receiver setup of proposed motion capture system.



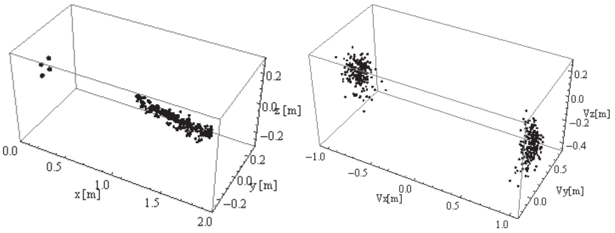
(a) Conventional method (b) Our method

Fig. 4 Localization techniques in the case where obstacles interference exists.



(a) Velocity error and standard deviation (b) Distance error and standard deviation

Fig. 5 Result of one dimensional experiments.



(a) 3D position (four points in the left side show positions of sensors) (b) 3D velocity vector

Fig. 6 Experimental result of three-dimensional experiment (± 1.0 m/s).