Design and Implementation of an Automatic Followspot Tracking System

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ABSTRACT

For stage lighting, follow spot systems are in general manually operated, and therefore both labour intensive and expensive. This paper describes a 3rd year project as part of an electronics degree at the University of Southampton, which aims to automate a followspot tracking systems. The technique chosen utilises a wearable belt pack for the actor, which contains a radio receiver for synchronisation and an ultrasound transmitter, whose signal can be picked up by various stationary receivers on the stage. From these signals, the transport delay is determined, permitting the calculation the exact position of the pack by triangulation. The minimum accuracy of the system is around 10cm.

1. INTRODUCTION

Stage lighting can be a labour-intensive undertaking if actors operating on stage have to be followed closely by spot lights, and is often further complicated by additional tasks such as dimming or colour selection. Therefore, in order to decrease the efforts and costs in lighting, automatic followspot systems have been considered in the past and been commercialised as reported in e.g. [1, 10]. However, such systems are expensive and not affordable for amateur groups groups such as "Showstoppers", the University of Southampton's student theatre group. To fill this gap, an automatic followspot system was to be designed during the thrid year project on a four-year MEng course in Electronic Engineering at Southampton.

Several design approaches have been considered. The use of low-cost camera equipment in combination with object and motion detection was deemed difficult due to potential low lighting on stage and the possibility of obstruction of the actor by stage decoration or colleagues. A radio link in the 27MHz control band had been looked into in combination with a distance measurement based on carrier phase followed by triangulation based on distances from various — at least four — receiver units. In this case, the wavelength would have proven long enough in order to not cause ambiguituous solutions on stage. However, the high temporal resolution of at least 1 ns in the receiver would have strained the data acquisition and processing, in addition to problems with multipath propagation. A simulation using a stage with reflective sides resulted in localisation errors of more than a metre when correlation was used to determine the time delay and hence distance between antennas.

Therefore, an ultrasound link was selected, which offers low enough frequencies to permit sampling and data acquisition at a reasonable rate. For a burst-type 40kHz ultrasound signal, simulations resulted in an error of the order of 10^{-3}m when using cross-correlation at a sampling rate of 250kHz. Although ultrasound is also used in [1, 10] for localisation, it was deemed that the immense system cost of [1, 10] justifies the consideration of an alternative system implementation.

The paper is organised as follows. In Sec. 2, a system overview is provided. Implementational aspects will be addressed in Sec. 3. Finally, conclusions are drawn in Sec. 4.

2. SYSTEM OVERVIEW

The system setup is shown in Fig. 1, where the position of a belt pack on stage needs to be determined and tracked. In similar applications, the use of ultrasound for distance measurement and localisation has been suggested [1, 10], and was followed here. Our belt pack was designed to operate an ultrasound transmitter [4], while for the receiver units we have selected ultrasound transceivers [5] in order to retain the possibility of automatically calibrating the system. With the receivers high up the stage and the transmitter of the belt pack attached to the actors neck or head, the directivity of the ultrasound transmitter and receivers was found to be sufficient.

The ultrasound bursts from the transmitter are triggered via an RF link between the control unit and the belt pack, and are amplified, and passed through a wire link to the central control unit, where the signals are subjected to an analogue to digital conversion. The transmitted ultrasound signal consists of sine bursts at 40kHz of 5 cycles duration. After acquisition, the data has to be appropriately processed to extract accurate time delay information. This is performed by picking he main peak of the cross-correlation function

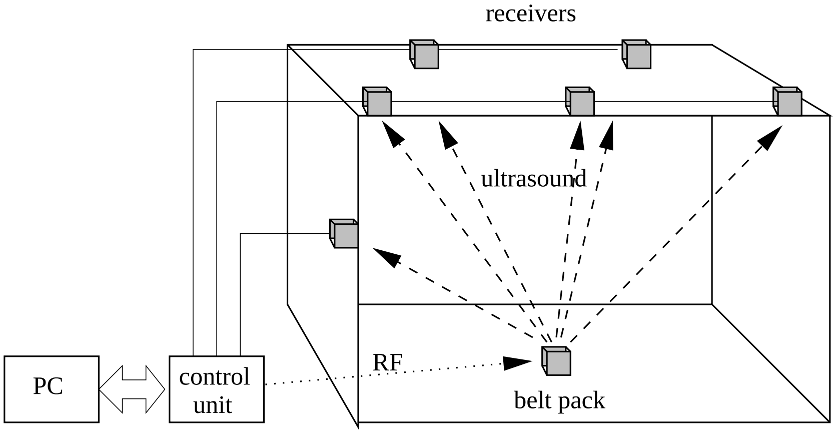

Fig. 1. System design setup for automatic followspot tracking [7].

between the burst signature and the received signal is evaluated [9]. This is necessary due to considerable noise interference, multipath effects in the propagation medium, and resonances in the ultrasound transceivers. The first peak of the cross-correlation function is used to estimate each time delay, and hence the distance of the transmitter from a specific receiver.

Based on a set of distances, via triangulation the position of the transmitter is determined in the DSP, solving a set of equations by Gaussian elimination. The result is checked against solutions in previous time instances, and translated into DMX protocol [6], which is used to drive the head lantern.

3. SYSTEM IMPLEMENTATION

Given the system specified in Sec. 2 and depicted in Fig. 1, details on the various system components and their implementation are provided in the following.

3.1. Radio Link

The radio transmitter between the control unit and the belt pack uses the 418 MHz band due to the availability of radio modules [2], while future system versions should rely on the licence free 433 MHz band. The modules where driven by programmable integrated circuits (PICs), which also form the main platform of the belt pack due to size restrictions and the relative simplicity of the required processing.

3.2. Ultrasound Data Acqusition

For the acquisition of the ultrasound signals in the receivers, the Texas Instruments 6 channel ADS8364 analogue to digital converter (ADC) was selected, sampling at 250kHz with 16 bit resolution [3]. An evaluation module of this ADC was connected via the expansion port of a C6711 DSK board [8], which thus controls data acquisition and offers the computational power required for cross-correlation calculations, the location solving, and the conversion to DMX protocol. Particularly the extraction of reliable timing information was impeded by ringing in the ultrasound transceivers, blurring the 125 μs long sine burst over an interval of approximately 10 ms. Usually, a set of bursts are to be transmitted in order to obtain a reliable cross-correlation estimate.

In terms of processing, taking cross-correlations is computationally expensive, given the riniging of 10ms, the requirement for several pulses, and a distance of up to 10m between the belt pack and a receiver. As a result, 2^{14} samples have to be recorded and cross-correlated. Given the computational benchmark of the C6711 without any further overheads, a refresh rate of only 3.5 Hz is achievable. Numerical efficiency can be exploited is the time delays between subsequent ultrasound bursts are know, the previous position is taken into account, and any multiplications with zeros on the reference signal are avoided. As a result, the DSP can operate at a refresh rate of 2.6 kHz and provide a sufficiently close temporal spacing of distance estimates.

3.3. Triangulation

For the estimation of the blet pack position, we utilise triangulation and assume that $N \geq 4$ receivers are used. Given the receiver positions $\mathbf{r}_i$, $i = 0(1)N-1$ and the distances d_i between the belt pack and the ith receiver, the unknown location of the belt pack $\mathbf{x}$ can be determined by triangulation, which is detailed below.

Based on the distance $d_i = \|\mathbf{r}_i - \mathbf{x}\|$, we consider the difference between two squared distances,

$$\|\mathbf{r}_i - \mathbf{x}\|^2 - \|\mathbf{r}_0 - \mathbf{x}\|^2 = d_i^2 - d_0^2 \quad \text{for } i = 1(1)N-1 \tag{1}$$

Considering the $N-1$ equations resulting from (1), we yield a matrix equation $\mathbf{Ax} = \mathbf{b}$ with

$$\mathbf{A} = \begin{bmatrix} 2(\mathbf{r}_1 - \mathbf{r}_0)^{\mathrm{T}} \\ 2(\mathbf{r}_2 - \mathbf{r}_0)^{\mathrm{T}} \\ \vdots \\ 2(\mathbf{r}_{N-1} - \mathbf{r}_0)^{\mathrm{T}} \end{bmatrix} \in \mathbb{R}^{N-1\times 3} \tag{2}$$

and

$$\mathbf{b} = \begin{bmatrix} d_1^2 - d_0^2 + \mathbf{r}_1^{\mathrm{T}}\mathbf{r}_1 - \mathbf{r}_0^{\mathrm{T}}\mathbf{r}_0 \\ d_2^2 - d_0^2 + \mathbf{r}_2^{\mathrm{T}}\mathbf{r}_2 - \mathbf{r}_0^{\mathrm{T}}\mathbf{r}_0 \\ \vdots \\ d_{N-1}^2 - d_0^2 + \mathbf{r}_{N-1}^{\mathrm{T}}\mathbf{r}_{N-1} - \mathbf{r}_0^{\mathrm{T}}\mathbf{r}_0 \end{bmatrix} \in \mathbb{R}^{N-1} \quad . \tag{3}$$

whereby $\mathbf{x}^{\mathrm{T}}$ denotes the transposition of $\mathbf{x}$.

With $\mathbf{A}$ and $\mathbf{b}$, the location of the belt pack is given by [11]

$$\mathbf{x} = (\mathbf{A}^{\mathrm{T}}\mathbf{A})^{-1}\mathbf{A}^{\mathrm{T}}\mathbf{b} \quad . \tag{4}$$

It is important to note that the accuracy of this solution depends on the condition number of $(\mathbf{A}^{\mathrm{T}}\mathbf{A})^{-1}$. However, since the system matrix is governed by the receiver locations, these locations can be selected to guarantee a well conditioned inverse, such that any measurement errors in the distances d_i, $i = 0(1)N-1$, are not further amplified.

3.4. Lamp Driver and Joystick Override

Additional circuitry was designed to interface the control unit with a PC for set-up of the system, as well as peripheral interfaces to the head lantern, the radio transmitter module, and the radio transmitter module employed for synchronisation of the system. This circuitry was based on two further PICs and a memory chip, and allows the automatic followspot tracking system output to be overwritten by a joystick input [7].

4. CONCLUSIONS

An automatic followspot tracking system has been introduced, which is based on distance estimation between a belt pack containing an ultrasound transmitter and several ultrasound receivers. Data acquisition and processing is performed using the ADS8364EVM ADC and the C6711 DSK respectively. While currently only a single belt pack is supported, ultimately the system is to accommodate several belt backs. Further, the calibration of the system is currently performed by hand, but it is anticipated that, based on the ultrasound transceivers in the receiver units in Fig. 1, an automatic calibration can be performed.

5. ACKNOWLEDGEMENT

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