

# Towards an Automatic Motion Coaching System

## Feedback Techniques for Different Types of Motion Errors

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**Abstract:** The development of a widely applicable automatic motion coaching system requires one to address a lot of issues including motion capturing, motion analysis and comparison, error detection as well as error feedback. In order to cope with this complexity, most existing approaches focus on a specific motion sequence or exercise. As a first step towards the development of a more generic system, this paper systematically analyzes different error and feedback types. A prototype of a feedback system that addresses multiple modalities is presented. The system allows to evaluate the applicability of the proposed feedback techniques for arbitrary types of motions in a next step.

## 1 INTRODUCTION

Over the last decade, we have seen a tremendous improvement of commercial real-time motion tracking devices. Systems like, e.g., *Microsoft Kinect*, *Nintendo Wii mote*, *PlayStation Move* provide low-cost solutions for end users in home environments. Despite the large market success of these systems, applications are mostly restricted to the gaming domain. However, potential application fields of such systems are manifold (see, e.g., Kasugai et al., 2010, Klack et al., 2010 or Heidrich et al., 2011).

One area that is becoming more and more important is computer-supported medical homecare (Ziefle et al., 2011) and in particular home rehabilitation. With the ongoing demographic changes in most industrialized countries (Röcker, 2013), we are currently heading towards a situation where the demand for personal rehabilitation assistance can not be met by medical personnel alone anymore.

In this context, automated motion coaching systems are a promising solution for addressing the increasing demand of home training and rehabilitation. Hence, our research goal is to develop an automatic motion coaching system that does not only adopt the role of a human trainer, but also provides additional benefits compared to existing training and rehabilitation concepts.

## 2 RELATED WORK

During the last years, several motion coaching systems have been developed. With the exception of Velloso et al. (2013), most authors focus on a special type of motion or exercise. This is due to the fact that there are tremendous differences between motions that have to be considered when analyzing motion data programmatically.

### 2.1 Results Gained in Previous Motion Coaching Projects

A review of several virtual environments for training in ball sports was performed by Miles et al. (2012). They stressed that coaching and skill acquisition usually involve three distinct processes (see Lawrence & Kingston, 2008): conveying information (i.e. observational learning), structuring practice (i.e. contextual inference) and the nature and administration of feedback (i.e. feedback frequency, timing and precision). Additionally, general possibilities when to provide feedback were identified. Concurrent feedback (during), terminal feedback (immediately following) or delayed feedback (some period after) can be used to assist the subject in correcting the motion. All of these aspects are worthwhile to be considered when developing a motion coaching system. The system presented in this paper

especially focuses on how and when to provide feedback.

A recent *concurrent feedback* approach was taken by Velloso et al. (2013) who developed “a system to communicate movement information in a way that people can convey a certain movement to someone else who is then able to monitor his own performance and receive feedback in an automated way”. Several types of visual feedback were included in the first prototype system and analyzed in a user study (n = 10). Based on the evaluation results, the authors identified the exploration of appropriate feedback mechanisms as an important topic for future research. Another example for *concurrent feedback* was presented by Matsumoto et al. (2007) who combined visual and haptic feedback to teach Shorinji (Japanese martial art). Subjects were asked to perform a movement which was projected on a wall. The correct angle of the wrist is enforced by a custom-engineered haptic device. Even though this device greatly improved the performance, it was very disturbing while performing the exercises due to its weight. This disadvantage is one of the reasons, why we refrain from using haptic feedback in our motion coaching system.

Chatzitofis et al. (2013) analyzed how to assist weightlifting training by tracking the exercises with a *Kinect* and using *delayed feedback*. They used 2D and 3D graphs to illustrate the captured performance metrics (angle of knees, velocity etc.). Nevertheless, there is still need for a human trainer to interpret those values in order to give feedback to the subject. We aim at providing feedback in such a way that there is no need for this type of professional assistance. The tennis instruction system developed by Takano et al. (2011) also uses a *delayed feedback* approach but the focus is put on the process of observational learning. To do so, the system searches a video database that contains expert movements by just performing the movement you want to learn with the *Wii mote*. Due to the absence of any explicit feedback, it is hard to determine how to actually correct the motion. Correction arrows or joint coloring are promising approaches to overcome this weakness (see section 3).

An example for *terminal feedback* can be found in (Chen & Hung, 2010) where the focus is put on the correct classification of motion errors by using a decision tree approach to determine an appropriate verbal feedback phrase. This phrase (e.g. “stretch out the arm”) is immediately provided after the completion of the motion. However, this only allows the correction of previously known and trained error types.

## 2.2 Categorization in the Design Space of Multimodality

In order to systematically analyze possible designs of motion coaching systems, the related work can be classified in a three-dimensional design space of multimodality (O’Sullivan & Igoe, 2004). The modality (visual, auditory, haptic) is chosen depending on the type of sense that the computer or human needs to perceive or convey information. The remaining classification is performed according to the following rules:

- [Input, Control] - The subject interacts with the system to control its function.
- [Input, Data] - The system perceives the subject performing the exercise.
- [Output, Control] - The system gives explicit instructions to the user (e.g., “move faster”).
- [Output, Data] - The system conveys certain performance metrics to the user that allow to improve the motion by interpreting those values (e.g., tachometer, traffic lights).

Note that a single system generally consists of multiple points in this design space (represented as a connected series of points).

This paragraph exemplary describes how a system is classified in the design space of multimodality (see Figure 1). For example, the system developed by Chatzitofis et al. (2013) can be controlled with mouse and keyboard (haptic input of control), visualizes performance metrics (visual output of data) and captures motion data by using the *Kinect* system (visual input of data).

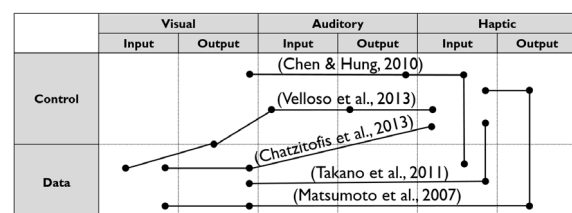


Figure 1: Classification of related work in the design space of multimodality. One system is represented by a connected series of points. The classification is partly based on the modality (visual, auditory, haptic) that the system uses for communication purposes.

In some cases, the differentiation between output of control and data is not unambiguous. Nevertheless, this can still be visualized. For example, in (Velloso et al., 2013) the output of an arrow indicating the direction in which to move the left or right arm can be regarded as both, output of data and control. In

the following, this type of visualization will be referred to as output of control.

### 3 MOTION ERRORS AND FEEDBACK TYPES

#### 3.1 Spatio-Temporal Motion Errors

The first step when thinking about how to provide motion error feedback is to become aware of different types of motion errors (i.e. deviation between a template and comparison motion) that need to be addressed. To that extent, it is obvious to differentiate between the spatial and temporal dimension. When just considering the spatial dimension, there are three main types of motion errors that can occur. First, the *absolute position* of a joint can be wrong (i.e. the coordinates of the left knee are expected to be  $[x, y, z]$  but are  $[x', y', z']$ ). When only the spatial collocation of several joints is important, the *relative position* of them should be taken into account instead. For example, a motion coaching system for a clapping motion should not pay attention to the absolute positions of the hands as it is only important that the palms touch each other. The last main error type that was identified is a *wrong angle* between the connections of three neighboring joints (e.g., stretching the arm implies an angle of  $180^\circ$  between the shoulder, elbow and hand). Naturally, the angle is influenced by the actual positions of the joints, but it is expected that a different type of visualization is required depending on whether the focus is put on the correction of an angle or the absolute joint positions. However, in a real world scenario the spatial dimension is always considered in combination with the *temporal dimension*. This allows to additionally find wrong execution speeds.

#### 3.2 Feedback Techniques

In a next step, several general ways to provide feedback by using different modalities were elaborated (see Figure 2). The most natural but technically the most complex way when using the visual channel is to either extract only the human body or to use the complete real scene and overlay it with visual feedback (e.g., colored overlay of body parts depending on the distance error). The natural scene reduces the cognitive load for the subject as the mapping between the real world and the visualization is trivial. Displaying the human body as a skeleton to represent the motion makes this mapping a bit harder but

allows to put the focus on the motion itself. To compare a template with a comparison motion, the abstracted skeletons can be visualized side by side or in an overlaid manner. It is expected that the overlaid view is mainly applicable when trying to correct very small motion errors. At an higher abstraction level, performance metrics such as speed or distance deviation per joint or body part can be calculated and displayed textually or graphically (i.e. with the aid of charts). All these feedback types are referred to as visual output of data as there is no information on how to correct the motion and the subjects need to interpret those values to improve their motion. To overcome this weakness, it is desirable to be able to visualize instructions (i.e. visual output of control) that guide users in correcting their motion. Two possible approaches are simple textual instructions (Kelly et al., 2008) or graphical instructions such as arrows indicating the direction in which the motion should be corrected (Velloso et al., 2013).

Audio feedback can be used in several ways to give motion error feedback. Spoken instructions (i.e. auditory output of control) are one possible way to which most people are already used to from real training situations. Note that the bandwidth of the auditory channel is much lower than the one of the visual channel and therefore not much information can be provided in parallel. Nevertheless, this channel has the big advantage that it easily catches human attention and users do not have to look in a special direction (e.g., for observing a screen). In terms of auditory output of data, different parameters of sound (i.e. frequency, tone, volume) can be modified to represent special motion errors. A first step in this direction was taken by Takahata et al. (2004) in a karate training scenario.

Another important point of research is the question of how to motivate people to use a motion coaching system. As it is commonly accepted that the use of multiple modalities increases learning performance (see, e.g., Evans & Palacios, 2010), a motion coaching system should aim at addressing multiple senses. Therefore, several of the above ideas should be combined.

The use of haptic output devices is not treated as applicable for a motion coaching system that shall be used to teach a wide range of different exercises due to two main reasons. First, there is no reliable and generic way to translate instructions into haptic patterns (see, e.g., Spelmezan & Borchers, 2008). Second, specially adapted hardware is required to provide appropriate haptic feedback, which often is considered as disturbing (Matsumoto et al., 2007).

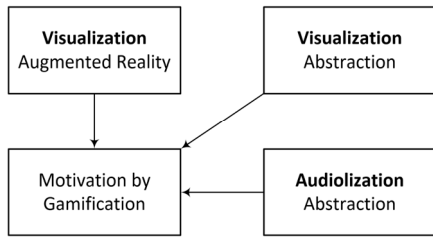


Figure 2: Possible ways for motion error feedback.

## 4 MOTION COACHING SYSTEM

To combine the ideas of motion errors and different types of motion feedback, a prototype system was implemented that enables first experiments with some of the proposed feedback types.

JavaFX was used as an underlying framework since it allows fast creation of user interfaces with JavaFX Scene Builder and provides built-in support for animations and charts. In order to enable concentrating on the visualization itself, the system takes two synchronized motion sequence files as input. Synchronized in this context means that frame number  $i$  in the template motion corresponds with frame number  $i$  in the comparison motion. The contained joint positions are normalized and allow to ignore different physiques. Figure 3 provides an overview of the system (joints that are not relevant for a special motion can be de-selected manually).

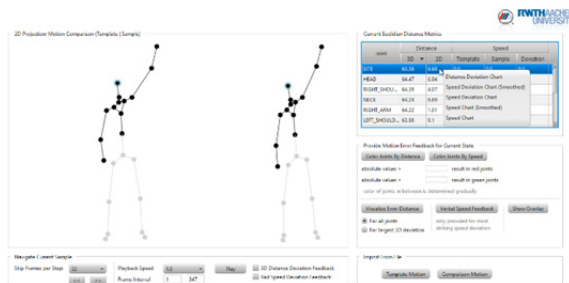


Figure 3: Overview of the motion coaching system.

For testing purposes, sample data collected from subjects performing a baseball pitching-motion were used.

### 4.1 Feature Overview

*Visual Output of Data I – Metrics (Textual):* The performance metrics illustrated in Figure 4 provide basic information such as 3D and 2D distance deviations per joint and a comparison of the template and sample speed per joint. Due to the perspective projection of the real-world 3D coordinates to the joint

positions in the visualized 2D skeleton on the screen, it may occur that there are large 3D deviations that are not recognizable in the skeleton representation. The data helps to get an understanding of this relation and allows for very detailed motion analysis. Nevertheless, this high precision is not necessarily needed for a motion coaching scenario and a subject may only use this type for terminal or delayed feedback.

Joint	Distance		Speed		
	3D	2D	Template	Sample	Deviation
LEFT_LEG	82.42	3.84	1.44	1.86	0.43
LEFT_FOOT	81.34	12.99	0.21	0.56	0.35
LEFT_FOOT_HL	80.02	7.62	0.23	0.56	0.32
RIGHT_LEG	78.57	11.63	3.16	2.05	-1.11
SITE	78.24	9.61	3.17	3.51	0.34
HEAD	77.12	8.29	3.08	3.36	0.29

Figure 4: Distance and speed metrics for a single pair of frames for currently loaded motion sequences.

*Visual Output of Data II – Metrics (Graphical):* Charts are used to visualize distance and speed metrics over time. Multiple joints can be selected to be included in a single chart to compare the respective deviations. This allows for an extensive joint clustering analysis, e.g., for finding out which joints can be clustered together as bodypart in order to provide feedback on a per-bodypart instead of a per-joint basis. From a motion coaching perspective, this type of feedback is mainly suited for terminal or delayed feedback. It is expected that the acceptance depends on the subject’s spatial abilities. Figure 5 exemplarily visualizes the speed deviation (between the template and comparison motion) of two different joints for a small frame interval.

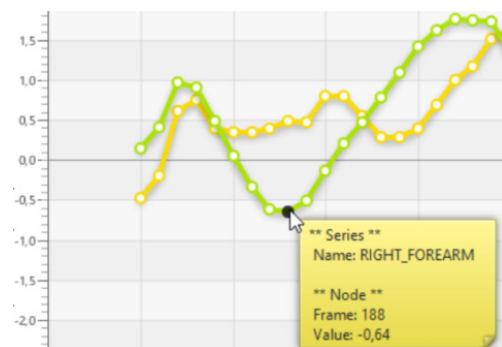


Figure 5: Speed deviation chart for right forearm (selected series) and right hand.

As real world data is often subject to large fluctuations, values are smoothed for visualization purposes



by calculating a weighted average for the  $k$ -step neighborhood ( $k$  between 5 and 10).

*Visual Output of Data III – Colored Joint Overlay:* The developed system allows to define a lower and an upper threshold value. All joints with deviations larger than the upper threshold value are colored in red, all joints with deviations smaller than the lower threshold value are colored in green (applicable for speed and distance deviations). The coloring of joints with values in between those thresholds is determined gradually (i.e. vary from red over orange to green). An example can be found in Figure 6 (left skeleton) where the largest deviations occur for joints located on the right arm. This visualization approach can be used either for concurrent, terminal or delayed feedback and allows to easily determine joints with high deviations. Nevertheless, the determination of reasonable threshold values over time is technically hard and no information is given on how to correct the motion.

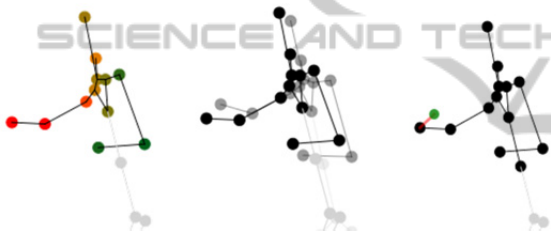


Figure 6: Exemplary skeleton-based distance error visualizations (left: colored joint overlay, center: overlay of template and comparison skeleton, right: static result of animated joint moving to its correct position).

*Visual Output of Data IV - Skeleton Overlay:* Visualizing the template and comparison skeleton in an overlaid manner (instead of side by side, which is the default behavior of the proposed system) turned out to be only suitable to correct very small motion errors. Otherwise the mapping between the intended and actual joint position is not directly visible. Often, it is hard to differentiate between the two skeletons. To overcome this weakness, the opacity value of the template is lower than the one of the comparison skeleton (see Figure 6, center).

*Visual Output of Control - Distance Error Animation:* So far, no direct information on how to correct the motion was given. The initial idea of Velloso et al. (2013) that used directed arrows to indicate how to correct the motion was adapted and replaced by an animated joint that moves to its correct position and thereby gradually changes its color from red (wrong position) to green (correct target position is reached). Even though this is still a quite technical representation, this approach is considered

to be more natural than the representation using arrows (see Figure 6, right). Since the projected 2D position difference does not automatically reflect the 3D position difference, it is expected that the success of this method highly depends on the projection parameters. It is only applicable for terminal or delayed feedback.

*Auditory Output of Control - Speed Feedback:* To address more than one sense, auditory feedback was included as well. For the most striking speed deviation, a verbal feedback phrase is provided by using a text-to-speech library. However, even if humans are used to this type of auditory feedback, such a specific per-joint feedback is not applicable in practice. Therefore, several joints are clustered to body parts and feedback is provided accordingly (e.g. “Move your right arm faster” instead of “Move your right elbow faster”). Auditory Feedback in general is best suited for concurrent feedback. Speed feedback in particular suffers from the fact that it is too slow to convey feedback for very fast motions at the correct moment.

*Combination of Visual and Auditory Output of Data:* As stressed in the previous section, per joint speed feedback is regarded as too technical. In this approach that combines visual and auditory output, joints are clustered to body parts (by using the charts for analyzing deviation dependencies) and considered as a whole during motion error feedback. The animated illustration is embedded in a video playback of the motion sequences (see Figure 7) and supported by corresponding speech output. Note that the coloring allows to easily determine the affected body part and the blinking speed of the highlighted joints depicts the type of speed deviation (too fast: fast blinking, too slow: slow blinking).

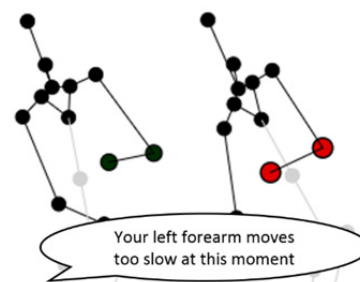


Figure 7: Example for embedded multimodal speed feedback in motion sequence playback (Note: text in speech bubble is provided by speech output and is not visualized).

## 4.2 Future Work

In a next step, an empirical analysis is required to evaluate the effectiveness and acceptance of the

different types of feedback. For this analysis, it is important to consider several types of motions and exercises and compare respective acceptance values. To do so, the integration of an automatic determination of appropriate projection parameters is required. Two of the proposed general feedback types (abstracted visualization and abstracted audiolization) were addressed in our prototype system. Additionally, first analogue approaches by using an augmented reality scenario should be anticipated. A last important research area to be worked on is the effect of using sounds and changing its parameters for motion error feedback.

## 5 DISCUSSION

This paper analyzed different ways to provide motion error feedback, a very specific aspect within the development of an automatic motion coaching system. This divide-and-conquer approach allowed us to focus on feedback techniques itself without struggling too much with implementation details that are not directly relevant at this point. It is expected that the results from this first prototype can be used for an initial evaluation that may allow to exclude several feedback possibilities or reveal the need for analyzing others in more detail. However, technology acceptance is a quite complex phenomenon (Ziefle et al., 2011) and the success of a motion coaching system does not only depend on the visualization alone. Consequently, final statements are only possible when a complete system has been developed and tested in detail. The development of such a system requires an interdisciplinary approach with scientific contributions from the fields of machine learning, computer vision, human-computer interaction and psychology.

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