AUFTAKT 4.0.1

by zplane.development

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Contents

1 AUFTAKT Documentation

1.1 Introduction

AUFTAKT is a beat tracking algorithm that is able to perform beat estimation even in drumless material and short audio snippets such as loops. The fourth version of the AUFTAKT SDK is able to not only follow tempo changes but also to cope with meter changes and rhythmically complex material. Beside the new capabilities, AUFTAKT v4 provides an improvement in downbeat tracking of roughly 25%, when compared with the previous version of AUFTAKT.

Based on a novel approach, AUFTAKT utilizes a deep neural network to perform beat tracking. The neural network estimates a probability for each point in the musical piece to be either a beat or a downbeat. From these beat probabilities, AUFTAKT then predicts the most likely sequence of beats in the musical piece using a statistical model. An overview of the algorithm is shown below.

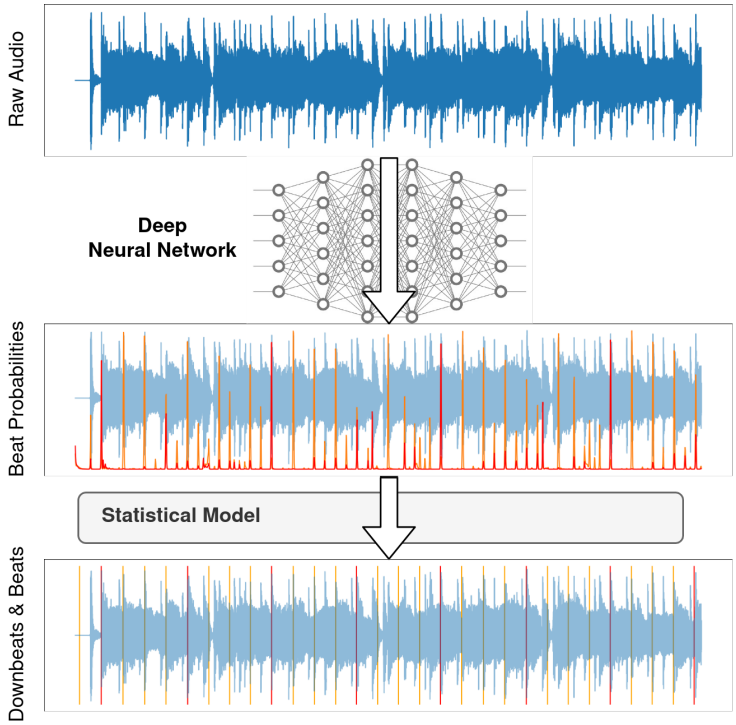


Figure 1: Overview of the beat tracking algorithm

This document contains all information you need to get started and use AUFTAKT to the best of its abilities. The documentation structured as follows: After introducing what is new in this version of AUFTAKT, the API is described. At the core of the A↩ PI description is a usage example taken from the aufTAKTClMain.cpp file, which is included in this package to get you started as quickly as possible. Afterwards, a brief description of the pre-compiled command line application delivered with the SDK is given. This can be used to quickly and easy get results from AUFTAKT. What follows is

a detailed documentation of the AUFTAKT interface and all of the methods and structs contained within.

1.2 What's new in AUFTAKT v4

Apart from its aforementioned completly new designed algorithm AUFTAKT also introduces a new interface structure, when compared to previous zplane SDKs. The restructuring made the interface more clear and easier to use. Instead of using virtual methods and having to deal with pointers to instances, we now use the pImpl idiom. Meaning you can now directly instantiate the aufTAKT class. After the instantiation it just needs one call to the **aufTAKT::initialize()** method and the instance is ready to be put to use. We were also able to reduce the interface to just one header (leaving out a dedicated interface for results), which makes obtaining beat-tracking results from the AUFTAKT class simpler and more intuitive than in previous versions of the SDK.

1.3 API Documentation

1.3.1 Memory Allocation

The AUFTAKT SDK does not allocate buffers handled by the calling application. The input buffers have to be allocated by the calling application. The input buffer size of the OnsetDetection module shouldnt exceed a value of 16384 frames. Audio buffers are allocated as double arrays of [channels][SamplesPerChannel].

1.3.2 Naming Conventions

When talking about frames, the number of audio samples per channel is meant. I.e. 512 stereo frames correspond to 1024 float values (samples). If the sample size is 32bit float, one sample has a memory usage of 4 byte.

1.3.3 Required Functions

The following methods have to be used (in the order they appear here) to obtain beat tracking results from AUFTAKT. For details see the documentation of the methods and the example below.

- **aufTAKT::initialize (float sampleRate, int numberOfChannels, int max↩ BlockSize, float minTempoInBPM = 60.f, float maxTempoInBPM = 240.f, std::vector<int> meters = {3, 4});**
  - Initalizes an AUFTAKT instance. For parameters s. below. Defaults should work well for most applications
- **aufTAKT::preProcess (float const* const* const inputBuffer, int number↩ OfFrames);**
  - Feed audio data (samples) to AUFTAKT. For parameters s. below
- **aufTAKT::finishPreProcessing()**
  - Finish the pre processing stage and prepare AUFTAKT for beat estimation
- **aufTAKT::process()**

  - Estimate beats and downbeats

- **aufTAKT::getResult (std::vector<aufTAKT::Beat>& beatResult)**
  - Fill a pre-allocated vector of **aufTAKT::Beat** structs with the result

1.3.4 C++ Usage example

The complete code referenced to here can be found in the example source file aufTAKTClMain.cpp. In the first step, an instance of aufTAKT has to be created. Note that this is different to how you would create an instance of previous zplane SDKs. After instantiation, we use the **aufTAKT::initialize()** method to prepare AUFTAKT to be used.

```
aufTAKT aufTaktInstance;
aufTaktInstance.initialize (inputFile.GetSampleRate(),
                            inputFile.GetNumOfChannels(),
                            blockSize);
```

In this case, we initialize the instance of AUFTAKT simply with its default parameters. Other parameters than the ones shown here are the minimum and maximum tempo AUFTAKT operates at, as well as the meters it considers when estimating downbeats. For details on these parameters see the documentation of **aufTAKT::initialize()** or **aufTAKT::setBeatTrackingParams()**. After initialization we call the **aufTAKT::preProcess()** method feeding AUFTAKT blocks of audio data. This function could for example be called several times from e.g. a while-loop that runs as long as there are still samples available for AUFTAKT.

```
    const aufTAKT::Error_t preProcessingError =
        aufTaktInstance.preProcess (inputBuffer, numFramesRead);
```

Once all available blocks have been fed to AUFTAKT we can now call the **aufTAKT::finishPreProcessing()** method to prepare AUFTAKT for the beat and downbeat estimation.

```
const aufTAKT::Error_t errorFromFinishPreProcessing =
    aufTaktInstance.finishPreProcessing();
```

This method contains roughly half of AUFTAKT's computational complexity. The other half of the computation happens once the process method is called subsequently:

```
const aufTAKT::Error_t errorFromProcess = aufTaktInstance.process();
```

After **aufTAKT::process()** has been called the results are now available for you to retrieve. To get the beat results one first has to allocate a vector of **aufTAKT::Beat** structs and subsequently pass it on to the **aufTAKT::getResult()** method. Similarly one can retrieve the estimated tempo via **aufTAKT::getOverallTempo()**.

```
std::vector<aufTAKT::Beat> beats;

aufTaktInstance.getResult (beats);

float tempoInBPM = -1.f;
aufTaktInstance.getOverallTempo (tempoInBPM);
```

Each instance of **aufTAKT::Beat** in the returned vector contains the members **timeInS**, **beatCountInBar** as well as **numBeatsInBar** providing all needed information about the beats i.e. the exact point in time, the location within a bar and the current meter. The tempo is computed simply as a mean over the duration of the audio AUFTAKT was given. Therefore, if there are a lot of tempo changes present in the piece of music, this estimate does not represent the true tempo.

If you are not satisfied with the results AUFTAKT delivered initially, you have two possibilities to refine its estimation. The first and easier one is to use the **aufTAKT::setBeatTrackingParams()** method to narrow down or extend the range in which AUFTAKT performs its estimation. For example, if you have a piece of music at 110 BPM which AUFTAKT wrongly estimates to be 220 BPM, it could be sufficient to reduce the upper tempo bound (i.e. the parameter **maxTempoInBPM**) to something like 150 BPM. If you have more detailed information about the beat structure for example some input given by a user by tapping, you could use the aufTAKT::setKnownDownbeats method to provide this information to AUFTAKT as follows:

```
// instantiate a container for known downbeats
std::vector<aufTAKT::KnownDownbeat> knownDownbeats;
// append known downbeat to the vector
constexpr float knownDownbeatTimeInS = 5.42f;
constexpr float tempoFromTheKnownDownbeatOnwardsInBPM = 164.f;
knownDownbeats.emplace_back (knownDownbeatTimeInS,
                             tempoFromTheKnownDownbeatOnwardsInBPM);
// call known downbeats setter before calling process
const aufTAKT::Error_t errorFromSettingKnownDownbeats =
    aufTaktInstance.setKnownDownbeats (knownDownbeats);
```

After doing so, you will need to call **aufTAKT::process()** again and retrieve the new result as shown above. If you have this kind of information available anyhow, you could also give it to AUFTAKT before any estimation by calling the above method before any call to **aufTAKT::process()**.

1.4 Command Line Usage Example

The compiled example is a command line application that reads audio files in the WAV format and performs beat tracking on them. The command line application will write all estimated information to stdout. The bare minimum usage example would be:

```
aufTAKTCl -i path/to/input_file.wav
```

Optionally, aufTAKTCl can also write the results to text files of your choice. By passing file paths behind the -b and -d flags respectively, aufTAKTCl will write line separated beat and downbeat locations given in seconds respectively. When given a file path with the -r flag, aufTAKTCl will create a file in which every line contains the following information for each beat found:

```
<timeMarkerInS> | <beatCountInBar> / <numBeatsInBar>
```

For further information simply call

```
aufTAKTCl --help
```

1.5 Support

Support for the source code is - within the limits of the agreement - available from:

zplane.development

grunewaldstr. 83
d-10965 berlin
germany

fon: +49.30.854 09 15.0
fax: +49.30.854 09 15.5

@: info@zplane.de

2 Namespace Index

2.1 Namespace List

Here is a list of all namespaces with brief descriptions:

3 Class Index

3.1 Class List

Here are the classes, structs, unions and interfaces with brief descriptions:

4 File Index

4.1 File List

Here is a list of all files with brief descriptions:

5 Namespace Documentation

5.1 zplane Namespace Reference

Classes

- class aufTAKT

6 Class Documentation

6.1 zplane::aufTAKT Class Reference

`#include <aufTAKT/aufTAKT.h>`

Classes

- struct Beat
- struct KnownDownbeat

Public Types

- enum Error_t {
  kNoError, kMemError, kInvalidFunctionParamError, kNotInitializedError,
  kPreProcessNeverCalledError, kUnfinishedPreProcessingError, kNoResultAvailable↩
  Error, kEmptyResultError,
  kInvalidDownbeatTimeError, kDownbeatsOutOfOrderError, kDownbeatsToo↩
  CloseToEachOtherError, kInvalidTempoError,
  kInvalidMeterError, kInvalidDataChunkError, kUnknownError, kNumErrors }

Public Member Functions

- aufTAKT ()
- ~aufTAKT ()
- Error_t initialize (float sampleRate, int numberOfChannels, int maxBlockSize, float minTempoInBPM=60.f, float maxTempoInBPM=240.f, std::vector< int > meters=std::vector< int >())
- bool isInitialized ()
- Error_t preProcess (float const *const *const inputBuffer, int numberOfFrames)
- Error_t finishPreProcessing ()
- Error_t process ()
- Error_t getResult (std::vector< aufTAKT::Beat > &beatResult)
- Error_t getOverallTempo (float &tempoInBPM)
- Error_t setBeatTrackingParameters (float minTempoInBPM, float maxTempo↩
  InBPM, std::vector< int > meters)
- Error_t setKnownDownbeats (const std::vector< KnownDownbeat > &known↩
  Downbeats)
- Error_t clearKnownDownbeats ()
- Error_t getDataChunk (void *preAllocatedDataChunk)
- Error_t getDataChunkSizeInBytes (std::size_t &dataChunkSizeInBytes)
- aufTAKT::Error_t setDataChunk (void *dataChunk)
- Error_t reset ()

Static Public Member Functions

- static const char * getVersion ()
- static const char * getBuildDate ()

6.1.1 Detailed Description

Definition at line 41 of file aufTAKT.h.

6.1.2 Member Enumeration Documentation

Error_t `enum zplane::aufTAKT::Error_t`

Enumerator

kNoError	no error occurred
kMemError	memory allocation failed
kInvalidFunctionParamError	one or more function parameters are not valid
kNotInitializedError	instance has not been initialized yet
kPreProcessNeverCalledError	finishPreProcessing() can only be called if preProcess has at least been called once
kUnfinishedPreProcessingError	finishPreProcessing() has to be called before process() or setKnownDownbeat()
kNoResultAvailableError	process() method was never called, therefore there's no available result
kEmptyResultError	the result is empty, this is most likely caused by too little audio in the buffer
kInvalidDownbeatTimeError	given downbeat time is less than 0 or greater or equal than the audio length preprocessed by the algorithm
kDownbeatsOutOfOrderError	downbeats need to be given ordered by the time they appear
kDownbeatsTooCloseToEachOther↩ Error	downbeats must be spaced at least one bar away from each other with respect to their corresponding tempo and meter
kInvalidTempoError	given tempo in BPM outside of aufTAKT's range, s. docs.
kInvalidMeterError	given meter not in aufTAKT's meter range, s. docs.
kInvalidDataChunkError	data chunk was invalid
kUnknownError	unknown error occurred
kNumErrors	

Definition at line 44 of file aufTAKT.h.

```
45         {
46             kNoError,
47             kMemError,
48             kInvalidFunctionParamError,
```

```
49              kNotInitializedError,
50              kPreProcessNeverCalledError,
51              kUnfinishedPreProcessingError,
52              kNoResultAvailableError,
53              kEmptyResultError,
54              kInvalidDownbeatTimeError,
55              kDownbeatsOutOfOrderError,
56              kDownbeatsTooCloseToEachOtherError,
57              kInvalidTempoError,
58              kInvalidMeterError,
59              kInvalidDataChunkError,
60              kUnknownError,
61
62              kNumErrors
63          };
```

6.1.3 Constructor & Destructor Documentation

aufTAKT() `zplane::aufTAKT::aufTAKT ( )`

~aufTAKT() `zplane::aufTAKT::~aufTAKT ( )`

6.1.4 Member Function Documentation

clearKnownDownbeats() `Error_t zplane::aufTAKT::clearKnownDownbeats ( )`

Clear all known downbeats if any have been set. Otherwise this method does not have an effect.

Returns

Error_t: Returns an error code.

finishPreProcessing() `Error_t zplane::aufTAKT::finishPreProcessing ( )`

Finish and terminate the pre-processing step. Needs to be called once, before process() can be called.

Returns

Error_t: Returns an error code

getBuildDate() `static const char* zplane::aufTAKT::getBuildDate ( ) [static]`

getDataChunk() `Error_t zplane::aufTAKT::getDataChunk (`
`void * preAllocatedDataChunk )`

Returns internal analysis data after finished preprocessing in an pre-allocated memory chunk.

This can be used to save analysis data for later processing. The memory handling has to be done by the calling application. The size of pre-allocated memory can be retrieved by getDataChunkSizeInBytes(). Note that this does not include parameters or any KnownDownbeats previously set.

Parameters

preAllocatedDataChunk	Pointer to the start of the allocated block for the dataChunk

Returns

Error_t: Returns errors if called at wrong points in time e.g. if this method is called with checkpoint afterFinishedPreProcessing before finishPreProcess() was ever called it will return kUnfinishedPreProcessingError.

getDataChunkSizeInBytes() `Error_t zplane::aufTAKT::getDataChunkSizeInBytes (`
`std::size_t & dataChunkSizeInBytes )`

Returns the length in bytes to be pre allocated in order to properly call getDataChunk().

getOverallTempo() `Error_t zplane::aufTAKT::getOverallTempo (`
`float & tempoInBPM )`

Get the overall tempo of all audio in buffer. Note that this is the average over the whole audio previously processed. This estimate therefore might seem off, if multiple tempi are present in the piece of music given to aufTAKT.

Parameters

tempoInBPM	Reference to a pre-allocated float in which aufTAKT writes the estimated tempo in beats per minute

Returns

Error_t: Returns an error code

getResult() `Error_t zplane::aufTAKT::getResult (`
`std::vector< aufTAKT::Beat > & beatResult )`

Get the result of a beat and downbeat estimation. Can only be called after process() has been called.

Parameters

beatResult	pre-allocated and empty vector of beats, which will be filled inside this method.

Returns

Error_t: Returns an error code

getVersion() `static const char* zplane::aufTAKT::getVersion ( ) [static]`

initialize()
```
Error_t zplane::aufTAKT::initialize (
    float sampleRate,
    int numberOfChannels,
    int maxBlockSize,
    float minTempoInBPM = 60.f,
    float maxTempoInBPM = 240.f,
    std::vector< int > meters = std::vector< int >() )
```

Initialize an instance of aufTAKT. Must be called before using any of aufTAK↩ Ts functionality. If called on an already initialized instance of aufTAKT, the instance gets re-initialized. Please refer to setBeatTrackingParameters(.) if it's necessary to re-initialize.

Parameters

sampleRate	Sample rate of the input signal in Hertz.
numberOfChannels	Number of channels in the input signal.
minTempoInBPM	Lower bound for tempo for aufTAKT to consider. Must not be lower than 50 BPM.
maxTempoInBPM	Upper bound for tempo for aufTAKT to consider. Must not exceed 250 BPM.
meters	List of meters for aufTAKT to consider. E.g. 3 for 3/4, 4 for 4/4 but also 7 for 7/8. Must not contain elements less than 1 or greater than 10. Note that the computational complexity of parts of aufTAKT scale linearly with the number of beats i.e. with the sum of the elements of this vector. If this vector is empty (as here by default), it will be set to $\{3, 4\}$.

Returns

Error_t: Returns an error code.

isInitialized() `bool zplane::aufTAKT::isInitialized ( )`

preProcess() `Error_t zplane::aufTAKT::preProcess ( float const *const *const inputBuffer, int numberOfFrames )`

Pre-Process a block of audio. This function can be called multiple times in order to provide successive chunks of the input audio signal.

Parameters

inputBuffer	pointer to the input data chunk. inputBuffer[n] points to the n-th audio channel.
numberOfFrames	The number of audio samples in each audio channel of the provided input data chunk.

Returns

Error_t: Returns an error code

process() `Error_t zplane::aufTAKT::process ( )`

Perform beat and downbeat estimation. This is where the major chunk of computational load happens. After calling this method, getResult() can be called. If the afterwards obtained result was not correct, you can either set new parameters via setBeatTrackingParameters() or help aufTAKT with a clue given via setKnownDownbeats() before calling this method again.

Returns

Error_t: Returns an error code

reset() `Error_t zplane::aufTAKT::reset ( )`

Resets the state of the SDK to the same state as directly after calling initialize()

Returns

Error_t : Returns an error code.

setBeatTrackingParameters() `Error_t zplane::aufTAKT::setBeatTrackingParameters ( float minTempoInBPM, float maxTempoInBPM, std::vector< int > meters )`

(Re)set the parameters used for beat estimation.

Parameters

minTempoInBPM	Lower bound for tempo for aufTAKT to consider. Must not be lower than 50 BPM.

Parameters

maxTempoInBPM	Upper bound for tempo for aufTAKT to consider. Must not exceed 250 BPM.
meters	Vector of meters for aufTAKT to consider. E.g. 3 for 3/4, 4 for 4/4 but also 7 for 7/8. Must not contain elements less than 1 or greater than 10. Note that the computational complexity of parts of aufTAKT scale linearly with the number of beats i.e. with the sum of the elements of this vector.

Returns

Error_t: Returns an error code

setDataChunk() `aufTAKT::Error_t zplane::aufTAKT::setDataChunk ( void * dataChunk )`

Set a saved data chunk in order to recover a previous pre-analysis state.

Parameters

dataChunk	Pointer to data chunk
dataChunkSizeInBytes	Size of the data chunk

Returns

Error_t: If data recovery was performed without error, otherwise kInvalidData↩ Chunk

setKnownDownbeats() `Error_t zplane::aufTAKT::setKnownDownbeats ( const std::vector< KnownDownbeat > & knownDownbeats )`

This method can be used to incorporate any previous knowledge about downbeat positions. We use the aforementioned KnownDownbeat struct to represent a single downbeat. This method has to be called before a call to process() to reflect the changes in the beat/downbeat estimation. Calling this method successively simply replaces the last list of known downbeats.

Parameters

knownDownbeats	A vector of known or suspected downbeats given as instances of the KnownDownbeat struct

Returns

Error_t: Returns an error code.

The documentation for this class was generated from the following file:

- aufTAKT/aufTAKT.h

6.2 zplane::aufTAKT::Beat Struct Reference

`#include <aufTAKT/aufTAKT.h>`

Public Attributes

- float timeInS

  time marker corresponding to this beat in seconds
- unsigned int beatCountInBar

  beat number in the bar, e.g. 1 for a downbeat etc.
- unsigned int numBeatsInBar

  number of beats in the enclosing bar i.e. the meter e.g. 4 for 4/4 but also 7 for 7/8 etc.

6.2.1 Detailed Description

Struct representing instances of beats in a result
Definition at line 127 of file aufTAKT.h.

6.2.2 Member Data Documentation

beatCountInBar `unsigned int zplane::aufTAKT::Beat::beatCountInBar`
beat number in the bar, e.g. 1 for a downbeat etc.
Definition at line 129 of file aufTAKT.h.

numBeatsInBar `unsigned int zplane::aufTAKT::Beat::numBeatsInBar`
number of beats in the enclosing bar i.e. the meter e.g. 4 for 4/4 but also 7 for 7/8 etc.
Definition at line 130 of file aufTAKT.h.

timeInS `float zplane::aufTAKT::Beat::timeInS`
time marker corresponding to this beat in seconds
Definition at line 128 of file aufTAKT.h.
The documentation for this struct was generated from the following file:

- aufTAKT/aufTAKT.h

6.3 zplane::aufTAKT::KnownDownbeat Struct Reference

`#include <aufTAKT/aufTAKT.h>`

Public Member Functions

- KnownDownbeat (float downbeatTimeInS, float tempoFromTheDownbeatOnwards↩ InBPM, unsigned int meter=4, float includedTempoRangeDeltaFromDownbeat↩ InBPM=20.f)

Public Attributes

- const float downbeatTimeInS
- const float tempoFromTheDownbeatOnwardsInBPM
- const unsigned int meter
- const float includedTempoRangeDeltaFromDownbeatInBPM

6.3.1 Detailed Description

Struct reflecting an instance of a known downbeat along with the tempo and meter corresponding to it. Needed for the setKnownDownbeat() method.

Please note that this struct does not implement any sanity checks of some kind e.↩ g. a downbeatTimeInS set to -1e10f will not cause an error here, but later on in the setKnownDownbeat() method. This is due to the fact that this class does not have any information about the current state of the aufTAKT algorithm.

Parameters

downbeatTimeInS	Point in time corresponding to the known (or suspected) downbeat.
tempoFromTheDownbeatOnwardsIn↩ BPM	Tempo corresponding to the known downbeat.
meter	Meter corresponding to the known downbeat. E.g. 3 for 3/4 or 4 to represent 4/4. aufTAKT's prediction will be bound to this given meter at any point after the knownDownbeat and before any following knownDownbeat which might comes with another meter.
includedTempoRangeDeltaFrom↩ DownbeatInBPM	After the known downbeat, aufTAKTs estimation will be bounded in the range tempoFromTheDownbeatOnwardsIn↩ BPM +/- includedTempoRangeDeltaFrom↩ DownbeatInBPM

Definition at line 183 of file aufTAKT.h.

6.3.2 Constructor & Destructor Documentation

KnownDownbeat() `zplane::aufTAKT::KnownDownbeat::KnownDownbeat (`
`float` *`downbeatTimeInS`*`,`

```
            float tempoFromTheDownbeatOnwardsInBPM,
            unsigned int meter = 4,
            float includedTempoRangeDeltaFromDownbeatInBPM = 20.f )  [inline]
```

Definition at line 186 of file aufTAKT.h.

```
190                : downbeatTimeInS (downbeatTimeInS),
191                  tempoFromTheDownbeatOnwardsInBPM (
    tempoFromTheDownbeatOnwardsInBPM), meter (
    meter),
192                  includedTempoRangeDeltaFromDownbeatInBPM (
    includedTempoRangeDeltaFromDownbeatInBPM) {};
```

6.3.3 Member Data Documentation

downbeatTimeInS `const float zplane::aufTAKT::KnownDownbeat::downbeatTimeInS`

Definition at line 192 of file aufTAKT.h.

includedTempoRangeDeltaFromDownbeatInBPM `const float zplane::aufTAKT::KnownDownbeat::includedTempoRangeDeltaFromDownbeatInBPM`

Definition at line 196 of file aufTAKT.h.

meter `const unsigned int zplane::aufTAKT::KnownDownbeat::meter`

Definition at line 195 of file aufTAKT.h.

tempoFromTheDownbeatOnwardsInBPM `const float zplane::aufTAKT::KnownDownbeat::tempoFromTheDownbeatOnwardsInBPM`

Definition at line 194 of file aufTAKT.h.

The documentation for this struct was generated from the following file:

- aufTAKT/aufTAKT.h

7 File Documentation

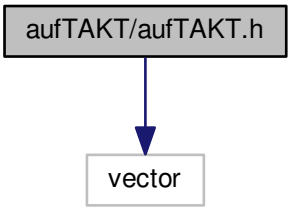
7.1 /work/project/docs/docugen.txt File Reference

7.2 aufTAKT/aufTAKT.h File Reference

interface of the aufTAKT class.

```
#include <vector>
```

Include dependency graph for aufTAKT.h:



Classes

- class zplane::aufTAKT
- struct zplane::aufTAKT::Beat
- struct zplane::aufTAKT::KnownDownbeat

Namespaces

- zplane

7.2.1 Detailed Description

interface of the aufTAKT class.

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