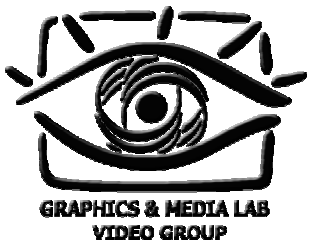


Video Codecs Comparison

Part 1: Methodology

Project head: Dmitriy Vatolin
Testing: Sergey Grishin
Translating: Daria Kalinkina, Stanislav Soldatov
Preparing: Nikolai Trunichkin

9 testing sequences!
11 days (260 hours) total compression time!
33 tested codecs!
2430 resulting sequences!

May 2003

CS MSU Graphics&Media Lab

Video Group

http://www.compression.ru/video/

Video Codecs Comparison
Part 1: Methodology

15 May 2003

Contents

Statistics

Codecs:

Processing time 258 hour

Number codecs – 27

Use 10 pointers in every bitrate

Number sequences – 9

Compression sequences 27*10*9=2430

Lossless codecs:

testing codecs – 6

number sequences – 6*9=54

processing time 7 hour

PSNR Metric

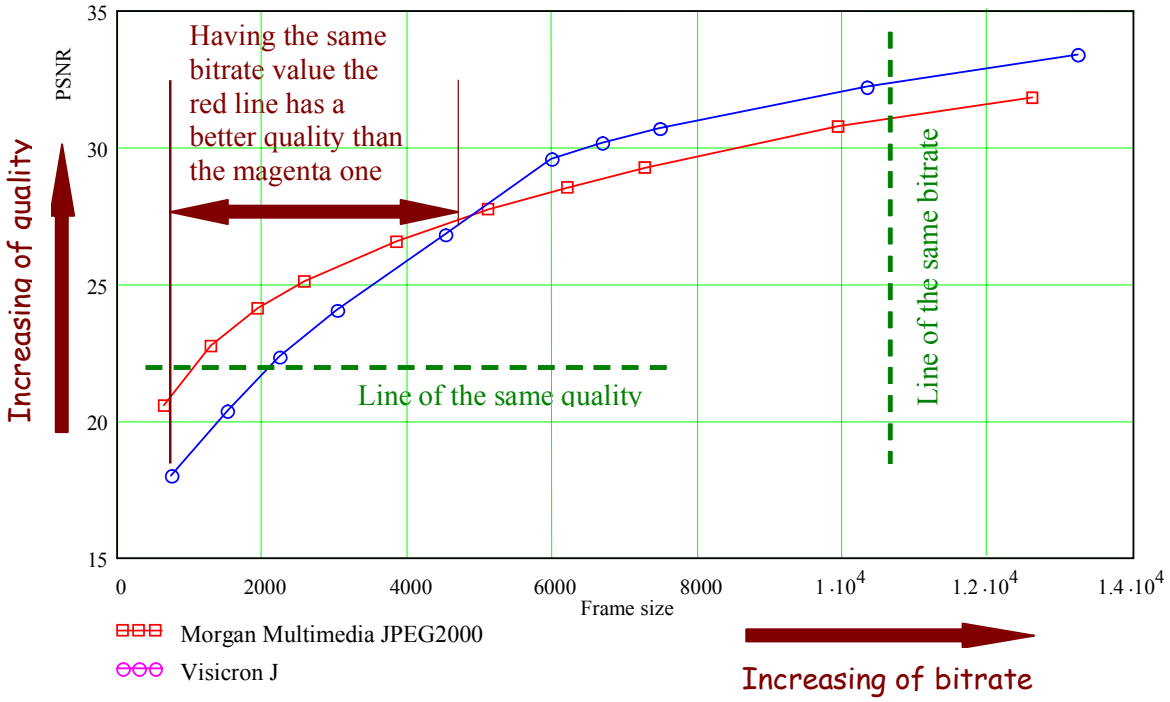
Metric description

PSNR (peak-to-peak signal-to-noise ratio) metric is used in this test as a criterion of compression quality estimation:

$$d(x,y) = 10 * \log_{10} \frac{255^2 * n^2}{\sum_{i=1,j=1}^{n,n} (x_{ij} - y_{ij})^2}$$

The advantage of using this metric is in dealing with a logarithmic scale. However it has a few drawbacks:

- Image gets strongly spoiled when brightness is lowered by 5 percent (eye will not tell the difference since different monitors have wider range of brightness setting).
- Images that contain so-called “snow” (sudden color changes of the separate pixels, weak stripes or moire pattern) will be considered almost unchanged.



На графике изображена зависимость показателя метрики от среднего размера кадра. Каждая ветвь соответствует определенному кодеку. Ветви построены на опорных точках, каждая из которых соответствует конкретному битрейту. Очевидно, на каждой ветви находится по десять точек (каждая последовательность сжимается на 10 настройках битрейта). Бывает, что кодек не удерживает битрейт и с разными настройками битрейта сжимает одинаково. В таких случаях, очевидно, на ветви кодека расположено менее десяти опорных точек. Для сравнения кодеков на этих графиках следует обращать внимание на то, как высоко расположены ветви кодеков. Чем выше находится ветвь – тем выше качество последовательности, сжатой данным

кодеком. На приведенном рисунке видно, что на низком битрейте качество последовательности, сжатой кодеком Morgan Multimedia JPEG2000 выше, чем у последовательности другого кодека. Однако, на высоком битрейте Visicron J сжал последовательность с меньшими потерями качества по сравнению с кодеком MM JPEG2000.

This diagram shows how metric index depends on the average frame size. Each curve relates to some codec. Curves are built on basic points; each of these points is connected with the specific bitrate. There are 10 points on each curve, which means that each video sequence has been compressed 10 times with different bitrate settings. Sometimes it happens that codec does not keep the bitrate that was set and compresses similarly with different bitrate settings. In this case there are less than 10 points on the curve. In order to compare codecs using this diagram, one should pay attention to the location of the curves relative to the Y axis. The higher the codec's curve is, the better the quality of the video sequence compressed by this codec is. On the picture above one can see that on small bitrate the quality of the video sequence compressed by Morgan Multimedia JPEG2000 is better than the quality of the video sequence compressed by Visicron J while Visicron J works better on high bitrate.

Meaning of the PSNR/Frame size (with drop frames) diagrams

Drop frame is a frame that is not compressed by codec. Instead of compressing it codec replaces this frame with the last compressed frame, which only requires on the byte-level setting a special flag in the code. This flag means that this frame is a drop frame and that it should be replaced with the previous frame during the play-back. If previous frame is also a drop frame, the current one is replaced with the last non-drop frame. Evidently the size of the flag is much less than the size of the encoded frame. So drop frames are means of lowering bitrate of the compressed video sequence.

Unlike the previously shown diagram type, PSNR/Frame Size (with drop frames) diagrams show dependence of Y-YUV PSNR metric on real average frame size – that is the result of dividing the size of the sequence on the number of non-drop frames. Frequently codecs generate several drop frames one after another, what affects the film rather unpleasantly: a static picture appears instead of the dynamic scene (slide show effect). In other words, instead of 5-6 different frames in the source video sequence, there are 5-6 identical frames in the compressed one. But it should be mentioned, that some codecs can use drop frames reasonably and make there presence in the sequence unnoticeable.

Ordinates of the basic points of the branches on the PSNR/Frame Size (with drop frames) diagrams are similar to the ordinates of the corresponding points on the PSNR/Frame Size (without drop frames) diagrams. Abscissas are different in case that these points relate to bitrate that made codec use drop frames. Abscissa of the point on the PSNR/Frame Size (without drop frames) diagram is a result of dividing the size of the sequence compressed with the corresponding bitrate by the number of all the frames in the sequence. So abscissas grow as bitrate grows and therefore the size of the sequence grows. Abscissa of the point on the PSNR/Frame Size (with drop frames) diagram is a result of dividing the size of the compressed sequence by the number of non-drop frames in the sequence. So abscissas of the points where drop frames were used are not equal on these two types of diagrams. As bitrate grows, the size of the compressed sequence also grows and the number of drop frames reduces. So the higher bitrate is the more non-drop frames there are in the sequence. If the size of the compressed sequence grows more slowly than the number of non-drop frames as the bitrate grows, abscissas of the corresponding points reduce. If on the contrary the size grows rapidly and the number of non-drop frames grows slowly, the abscissas of the corresponding points increase. For some codecs there is some characteristic bitrate value and beginning from it the size of the compressed sequence starts to grow faster than the number of non-drop frames. On the PSNR/Frame Size (with drop frames) diagram it corresponds to the top point of the Y-axis directed peak (this peak can be seen on the picture above).

On the PSNR/Frame Size (with drop frames) diagram one can easily see the bitrate, beginning from which codec stops generating drop frames. This bitrate relates to the point, beginning from which curves on the with/without drop frames diagrams concur with each other. But this bitrate actually can't be a criteria of codec quality estimation, because one codec generates drop frames correctly while the other makes drop frames` usage too visible. These diagrams do not show positions of the drop frames in the video sequence.

Obviously, complete concurrence of the branches on the with/without drop frames diagrams means that there are no any drop frames in the compressed video sequence.

When comparing video codecs using these two types of diagrams one should pay attention to how close to the Y-axis branches of the diagram with drop frames are located. The more on the left the branch is the less average frame size the video sequence has and therefore the greater fps there is at the output. So those codecs, whose branches are located more on the left, provide better fps at the output with the same quality.

Testing Procedure

Sequence of operations

Nine s took part in the testing (see below). Each sequence was compressed ten times with different bitrate settings (kbit/s):100, 225, 340, 460, 700, 938, 1140, 1340, 1840, and 2340. All the sequences were compressed in VirtualDub 1.4. So as a result, 90 sequences were generated for each codec. After that PSNR metric (L-LUV, LUV-LUV, Y-YUV, U-YUV, V-YUV, R-RGB, G-RGB, B-RGB, Average Delta Y-YUV) and the number of drop frames were calculated for each sequence. PSNR metric was calculated both for each frame and for the whole sequence (that is the average value for all the frames). Then diagrams of different types were built based on these values.

Testing rules

- If any errors occurred during compression, process of compression was done again.
- During testing the specific codec other codecs were not installed (except for the codecs installed by the operating system). So one can be sure that the right dll was used for both compression and decompression.
- Frames for the visual comparison were chosen (if it was possible) so that the distance between these frames and the last key frame was more than 20 frames.
- If it was possible, quality comparison was done according to the video sequences which were compressed with the same bitrate. Otherwise, sequences with close bitrate were used. This rule was kept in the frame-accurate and visual codecs comparison sections.
- A number of diagrams are not given for some sequences in the “PSNR Diagrams for All Video Codecs” section. These missing diagrams do not contain any principle information about the codec’s functionality, that can’t be seen on the other pictures given.
- Frames from the compressed sequences are given for some codecs in the “Methodology” section. But the specified bitrate is the bitrate that was set as an option before the compression, while the actual bitrate can be different. Often codecs are likely to increase the specified bitrate and that’s why it is not correct to compare pictures for different codecs.
- Features of codecs` functioning described in this article are true for the default options. In other words none of the options of the codec were changed during the testing, except for the bitrate option.
- All diagrams in the “Methodology” section were built for the “bus” video sequence.

Breaking of any of these rules is specially mentioned.

Codecs review

Codecs

CODEC	PRODUCER	VERSION
1. AngelPotion	AngelPotion	1.0
2. MPEG4	Microsoft	1.0, 2.0, 3.0
3. I.263	Intel	
4. Indeo Video	Intel	R3.2
5. MPEG4	Kristal Studio	Pack 4.3.3
6. Indeo Video	Ligos	3.2
7. Indeo Video	Ligos	4.5
8. Indeo Video	Ligos	5.11
9. VP	On2	3.2.0.1
10. Motion Wavelets	Aware	1.7
11. JPEG2000	Morgan Multimedia	1.0
12. JPEG	Morgan Multimedia	2.0
13. Cinepak	Radius	1.1
14. MPEG4 Video	Microsoft	1.0, 2.0
15. Xvid	XVID	2.1
16. Divx	DivXNetworks	3.1 fast motion
17. Divx	DivXNetworks	3.1 low motion
18. Divx	DivXNetworks	4.02
19. Divx	DivXNetworks	5.02
20. VSS	VANGUARD Software Solutions	1.2
21. D4	3IVX	4.0.3
22. Visicron Dynamic	Visicron Division	1.0.3
23. Visicron Static	Visicron Division	1.0.3
24. Visicron J mode	Visicron Division	1.0.3
25. H.264	VANGUARD Software Solutions	

Attention! For some codecs new versions are available that was not included into this test.

Lossless codecs

CODEC	PRODUCER	VERSION
26. JPEG	LEAD	1.0
27. GZIP	CamStudio	1.0
28. PICVideo	Pegasus	---
29. AVIzlib	Kenji Oshima	2.2.3
30. MSU lab beta	MSU Graphics & Media Lab	0.1.0
31. HuffYuv	Ben Rudiak-Gould	2.1.1

Video Sequences

Film	Number of frames	Size of the source film	Resolution and colorspace
1. bankomatdi	376	120286 K	704x352(RGB)
2. battle	1599	351268 K	704x288(RGB)
3. bbc3di	374	263400 K	704x576(RGB)
4. bus	150	20761 K	352x288(RGB)
5. foreman	300	38481 K	352x288(RGB)
6. helicopterdi	113	41112 K	704x352(RGB)
7. NDDP7di	188	90089 K	720x576(RGB)
8. susidi	374	235618 K	704x576(RGB)
9. tensdi	373	323308 K	704x576(RGB)

Video Sequences Used in the Testing

Bankomatdi

Picture 1. bankomatdi, frame 168

This clip is a fragment of the “Terminator-2” movie, which represents the scene near the cash dispenser. The clip is characterized by slow motion, very little change of background (in the second part of the clip camera slowly goes to the right) and comparatively high resolution. Since the motion in the clip is rather simple, codecs should not have any problems with compressing it.

Battle

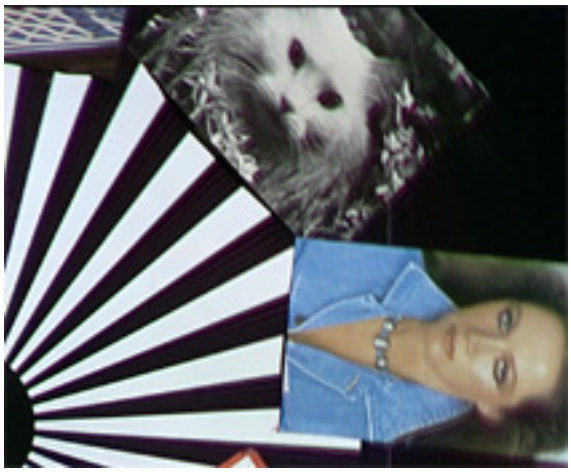
Picture 2. battle, frame 839

This clip is also a fragment of the “Terminator-2” movie, which represents the very beginning of the film. In the terms of compression this clip is the most difficult one among all other clips that took part in the testing. It is caused by three main reasons: constant changing of brightness because of the explosions and laser flashes, very quick motion and frequent changes of the scene that make codecs often compress frames as I-frames.

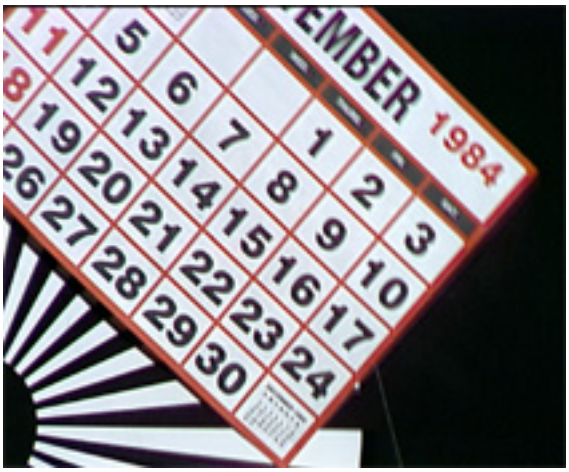
Picture 3. battle, frame 1079

Bbc3di

This clip is characterized by pronounced rotary motion. It contains a rotating striped drum with different pictures and photos on it. Quality of the compressed clip can be estimated by the details on these images.



Picture 4. bbc3di, frame 185



Picture 5. bbc3di, frame 258

Bus

Picture 6. bus, frame 130

This clip represents a bus which moves beside a lattice fence and is of much interest because this type of motion (motion beside a lattice object) is very difficult in terms of motion compensation. The quality of compression can be estimated by the details on the advertisement on the bus body. In addition there is a static text in the bottom right corner which also causes difficulties during compression. This clip is standard for codecs testing and is very popular.

Foreman

Picture 7. foreman, frame 77

Picture 8. foreman, frame 258

This is another famous clip. It represents a face with very rich mimicry. On the one hand motion here is not very intensive, but on the other it is disordered, not forward. Intricate character of motion creates problems for the motion compensation process. In addition camera is shaking which makes the image unsteady. In the end of the clip camera suddenly turns to the building site and there follows an almost motionless scene. So this clip also shows codec's behavior on a static scene after intensive motion.

Helicopterdi

Picture 9. helicopterdi, frame 46

This clip is characterized by forward motion. Both helicopter on the foreground and earth on the background move strictly forward. Change of background happens only once when the perspective changes. This clip is good for demonstrating co-dec's simple motion processing.

NDDP7di

Picture 10. NDDP7di, frame 13

This clip represents a dancer's performance and is characterized by rather quick and complicated motion. As in the "foreman" clip camera here permanently moves from one side to another making the image shaky. This clip is good for demonstrating codec's complex motion processing.

Susidi

Picture 11. susidi, frame 193

This clip is characterized by high-level noise and slow motion. In its first part the scene is almost static (the girl only blinks), then there is some motion (she abruptly moves her head) and then the scene becomes almost static again. Static background and little motion are supposed to result in the good motion compensation.

Tensdi

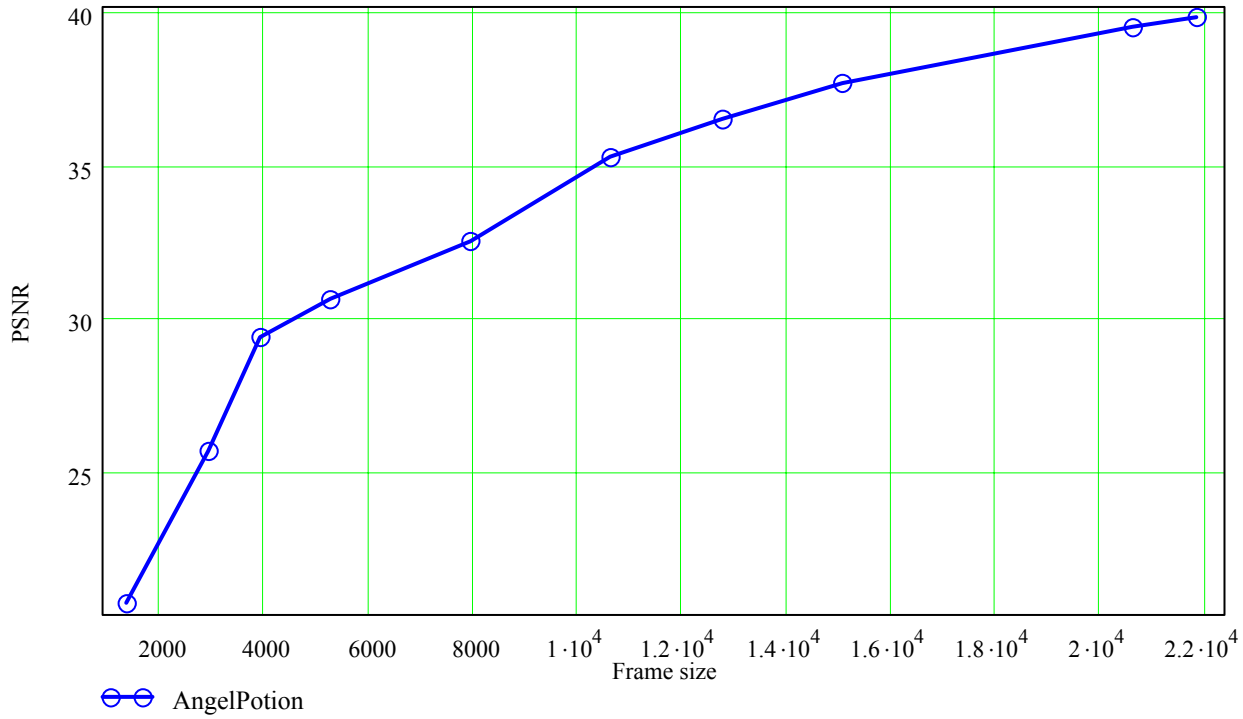
Picture 12. tensdi, frame 60

Picture 13. tensdi, frame 119

This clip represents ping-pong game. It is characterized by rather intensive motion (the ball and the players). The scene changes twice. This clip is another good example for demonstrating quality of motion compensation process.

Codecs Used in the Testing

AngelPotion v1



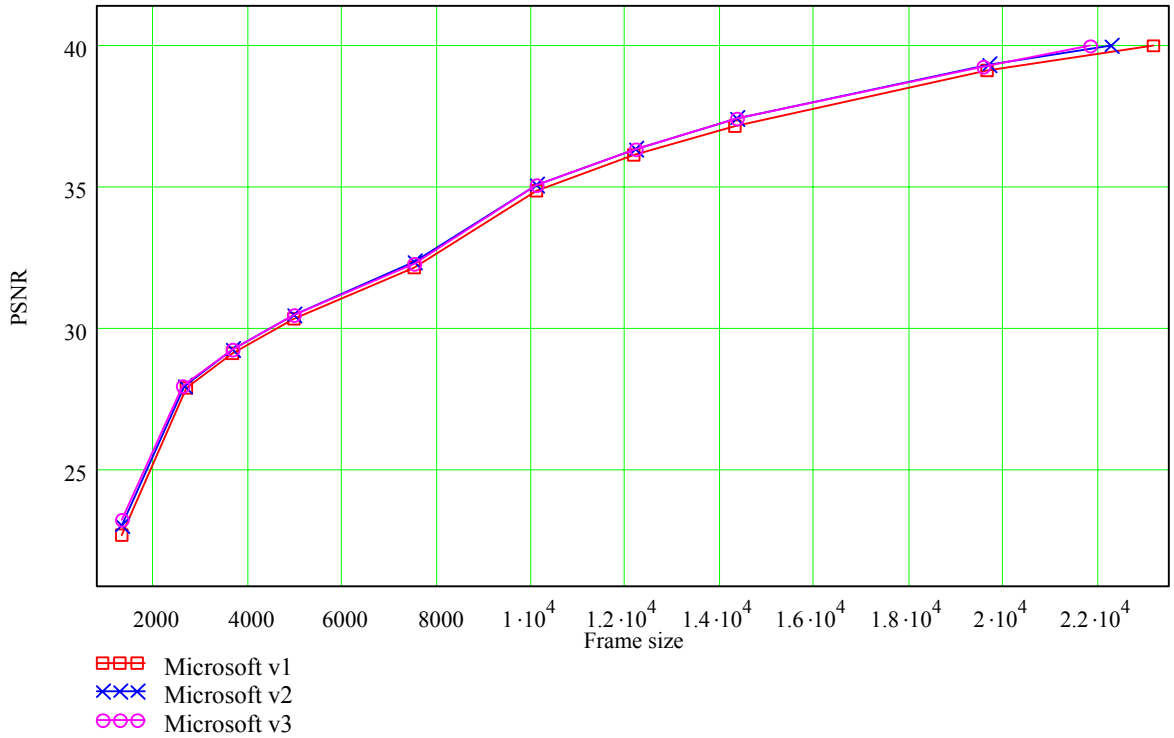
Picture 14. PSNR/FrameSize diagram for AngelPotion

This is another version of hacked Microsoft MPEG4 codec. According to some sources this codec is not recommended for installing because “it has tendency to change user’s structures”. This can lead to destruction or damage of the HKEY_CLASSES_ROOT\avifile section in the register and thus cause some applications for video playback to work unstably.

Picture 15. tensdi, frame 128, 340 kbps

Picture 16. bankomatdi, frame 178, 460 kbps

Microsoft Mpeg4 3688 Codec Versions v1, v2, v3

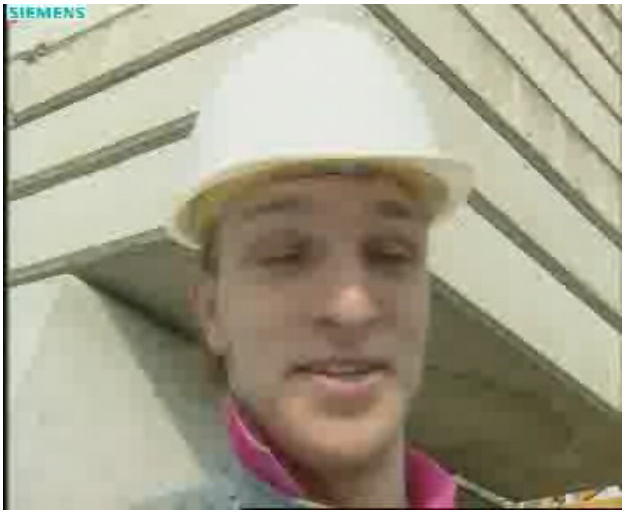


Picture 17. PSNR/FrameSize diagram for MS MPEG4 Codec v1, v2, v3

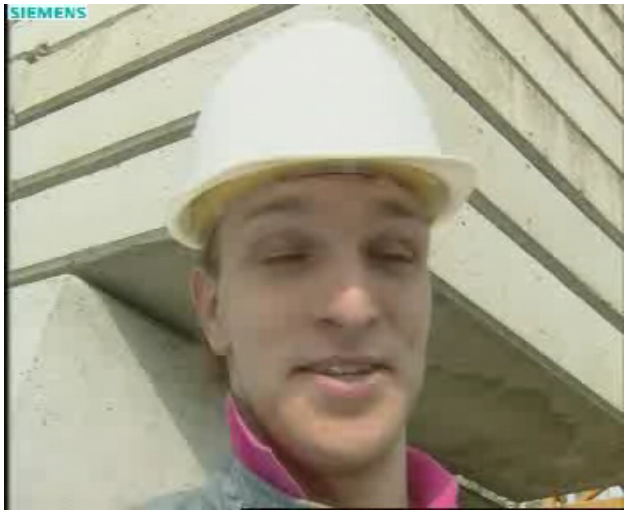
These are three versions of the original Microsoft codec (January 2003). This codec proved to be rather stable, no errors occurred during its free-running testing.

It uses drop frames what allows it to keep low bitrate. On high bitrate drop frames are not used.

In the same way as in the example below the codec compressed the nddp7di and tensdi sequences. Example is shown for v1.

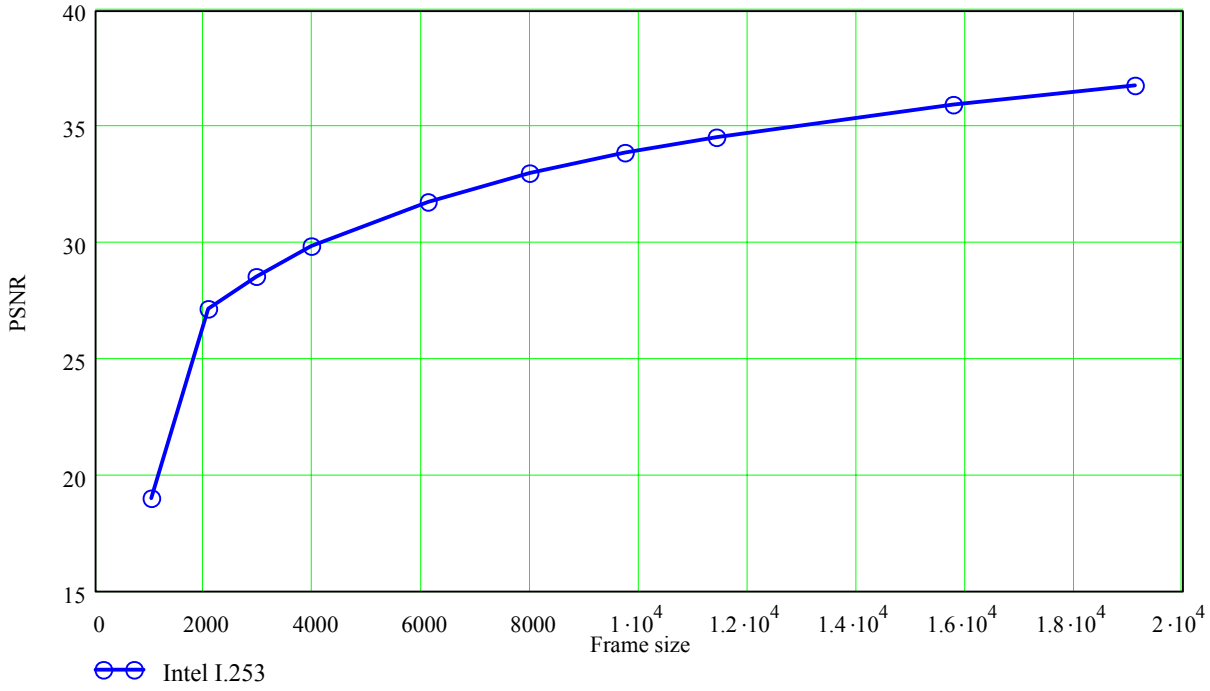


Picture 18. foreman, frame 1, 100 kbps



Picture 19. foreman, frame 1, 2340 kbps

Intel I.263

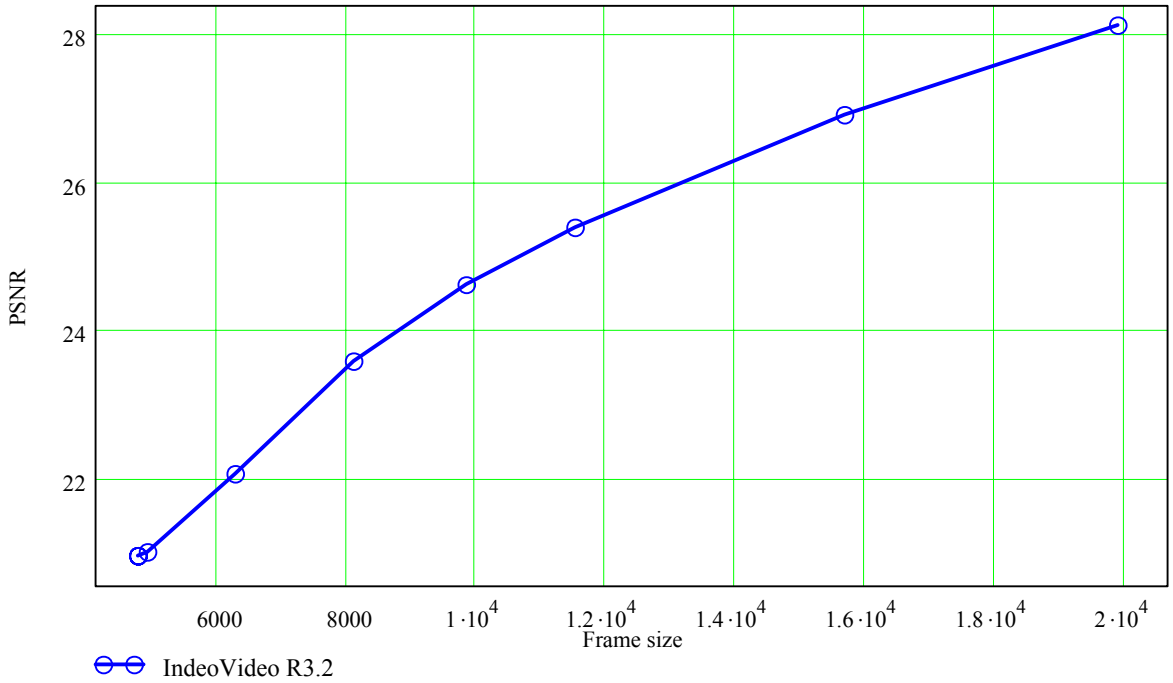


Picture 20. PSNR/FrameSize diagram for Intel I.263

This codec does not work with clips that have resolution more than 352x258. That's why it was tested only on the bus and foreman sequences that answer this requirement.

The characteristic feature of this codec is its duplicating the first frame of the sequence. Since the number of frames does not change, the last frame of the sequence is being lost during the compression. This fact was taken into consideration when calculating the metric.

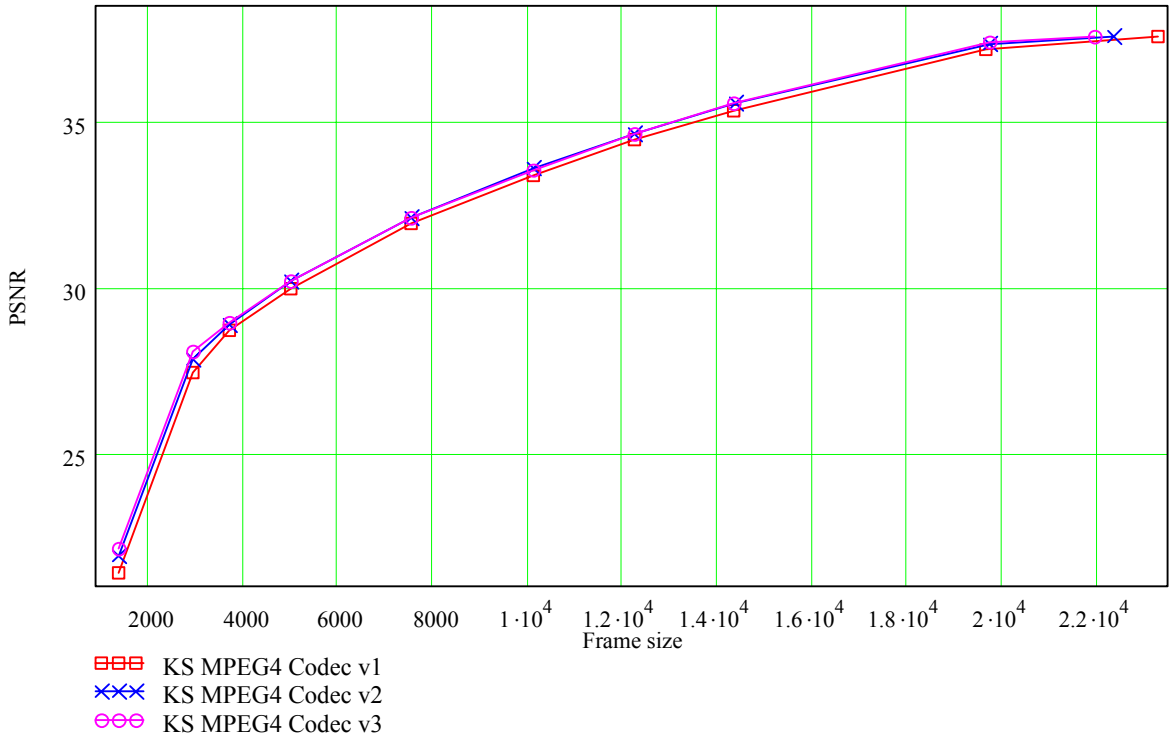
Intel Indeo Video R3.2



Picture 21. PSNR/FrameSize diagram for Intel Indeo Video R3.2

This codec works only with clips that have comparatively low resolution (bus.avi, foreman.avi). It's easy to see, that Y-PSNR for this codec related to the high bitrate reaches 28 dB while it reaches 40 dB for the majority of other codecs.

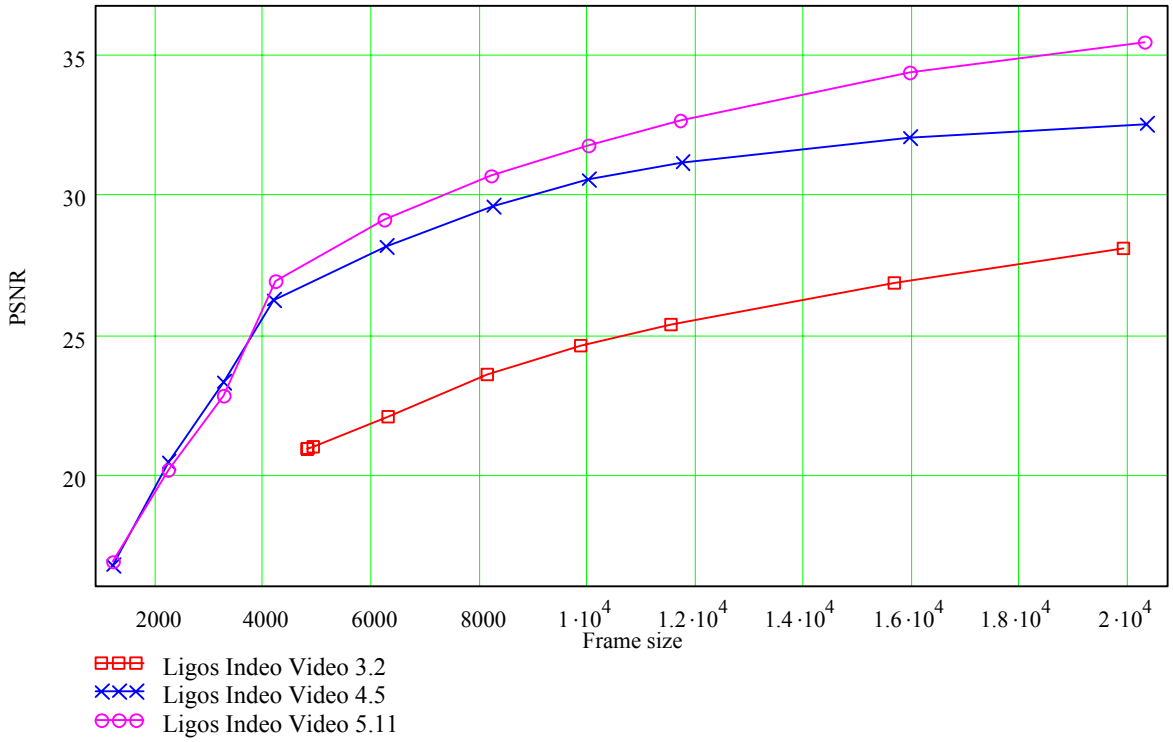
KS Mpeg4 Codec Versions v1, v2, v3



Picture 22. PSNR/FrameSize diagram for KS MPEG4 Codec v1, v2, v3

This is the one more version of the hacked Microsoft MPEG4 codec. It differs from the original one by its default settings, what in some cases leads to a better result.

Ligos Indeo Video Versions 3.2, 4.5, 5.11



Picture 23. PSNR/FrameSize diagram for Ligos Indeo Video 3.2, 4.5, 5.11

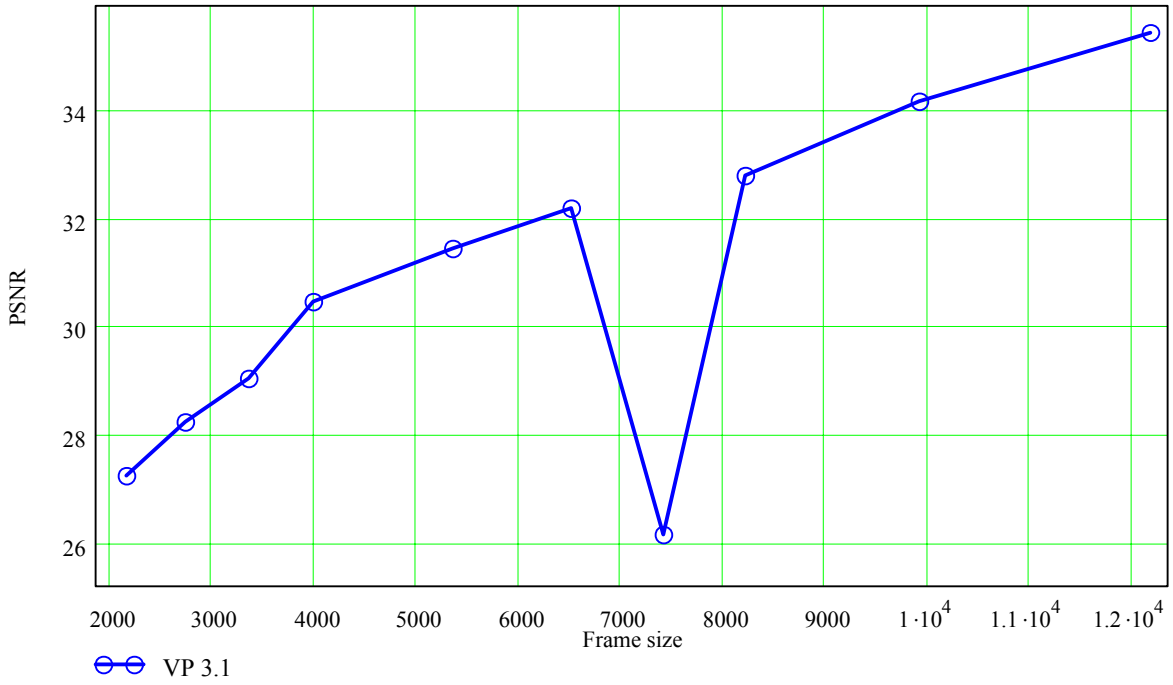
Version 3.2 does not support high resolution, so it was also tested only on the bus and foreman sequences. However this drawback was eliminated in its next versions, so they work with any testing sequences. The battle clip was incorrectly compressed by the version 4.5 with bitrate of 2340 kbps ("lost index error").

Pictures given below for comparison were compressed by the different versions of this codec with bitrate of 100 kbps. It should be mentioned that unlike Ligos 5.2, Ligos 3.2 did not generate any drop frames.

Picture 24. foreman, frame 14, 100 kbps (Ligos 3.2)

Picture 25. foreman, frame 14, 100 kbps (Ligos 5.11)

VP 3.1 Compressor



Picture 26. PSNR/FrameSize diagram for VP3.1

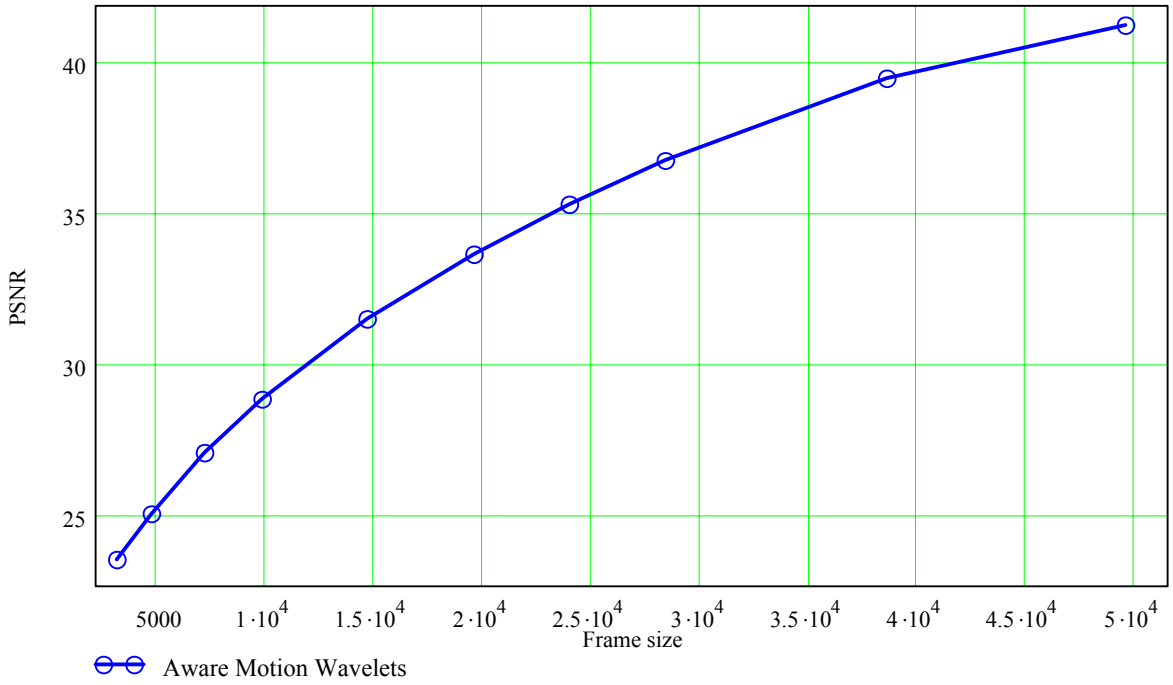
Failure of PSNR metric in the middle of the diagram is caused by the sudden deterioration of the compressed sequence quality (bus, 1140 kbps). Probably the correct result can be obtained after the repeated compression with the same bitrate. But on a whole this codec does not work stable.

Pictures below represent the same frame of the sequence compressed with different values of bitrate. Picture with low bitrate has block and Gibbs (artifacts on the edges of the objects) effects.

Picture 27. nddp7di, frame 64, 100 kbps

Picture 28. nddp7di, frame 64, 2340 kbps

Motion Wavelets By Aware



Picture 29. PSNR/FrameSize diagram for Motion Wavelets

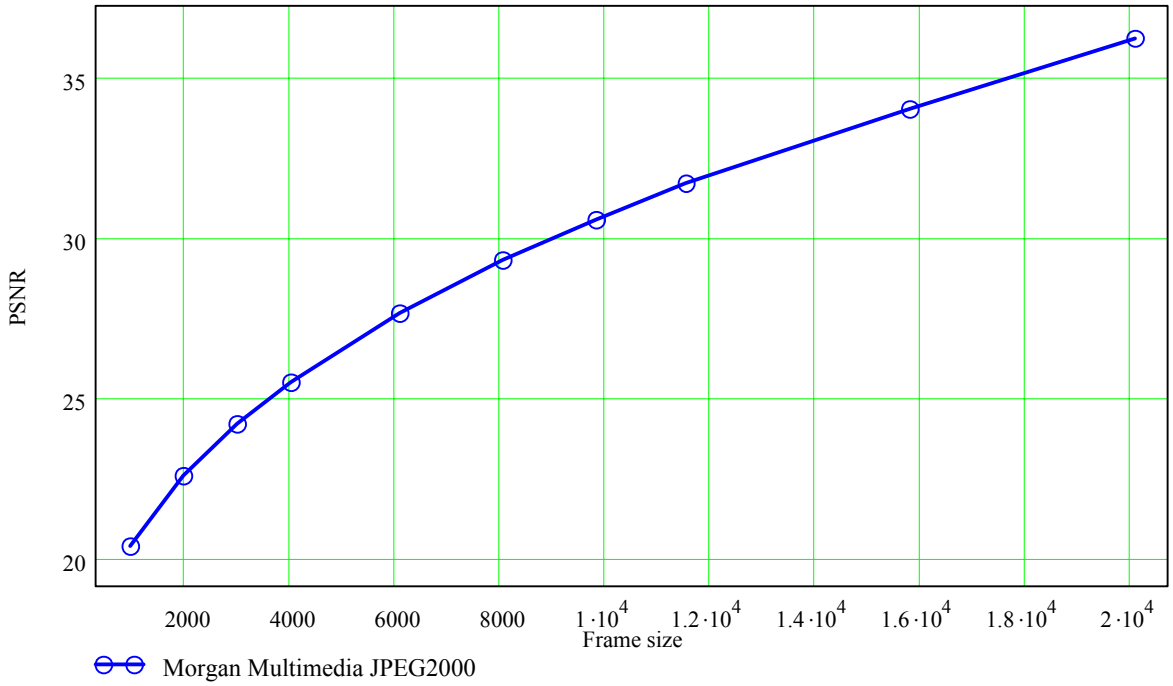
Codec's features:

- Despite the comparatively high values of PSNR metric this codec does not take place among the leaders, because it does not keep the bitrate making it from 10 to 25 times as much as it was set.
- Battle and susidi sequences were compressed with one bitrate value, so PSNR/FrameSize diagrams for these sequences turn into points.
- Errors of "lost index" type occurred several times during the testing.
- Codec's options do not let set bitrate less than 144 kbps.

It's easy to see, that this codec gives artifacts, which are typical for low bitrate, on comparatively high bitrate. For example the Gibbs effect can be seen on the picture below.

Picture 30. bankomatdi Motion Wavelets

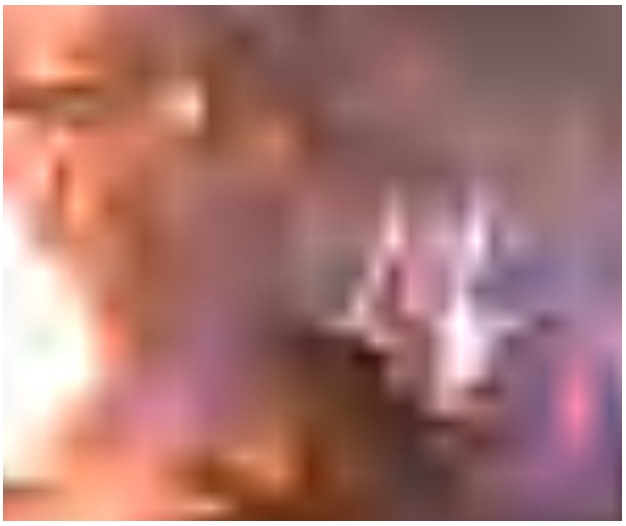
Morgan Multimedia JPEG2000



Picture 31. PSNR/FrameSize diagram for MM JPEG2000

This is a good enough version of the JPEG codec. There were three errors during its free-running testing, for some reasons the codec did not complete the compression process.

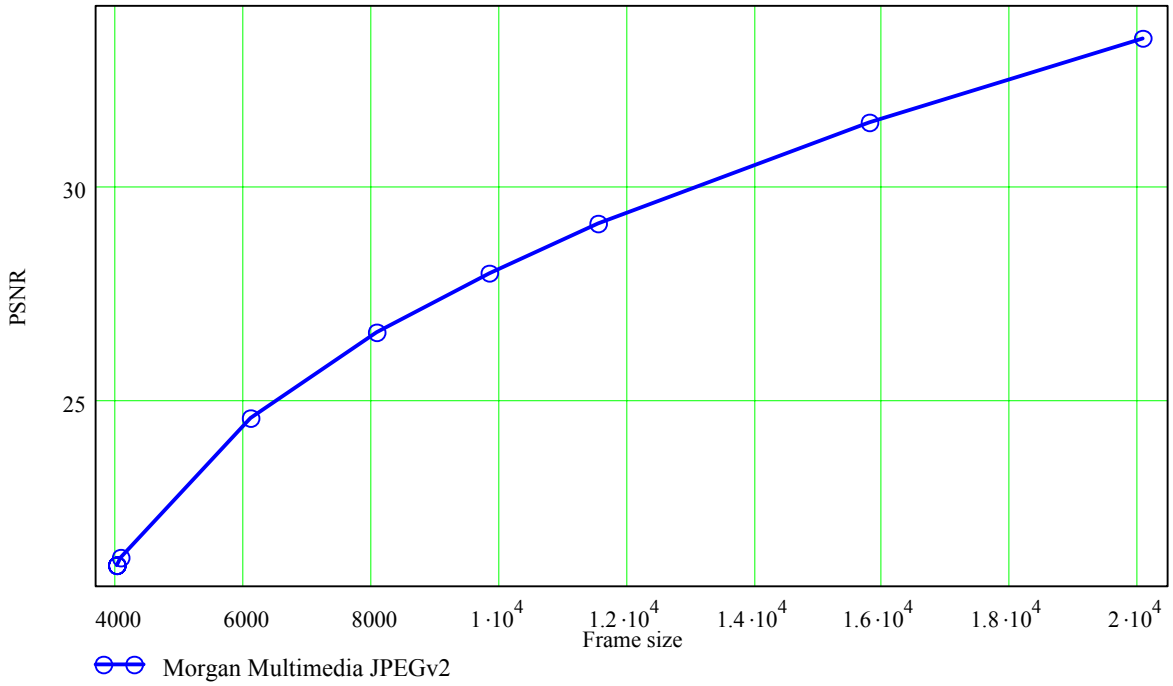
The pictures below represent the same frames from the sequence compressed with different bitrate values. The codec keeps the bitrate very well and makes the size of the frames almost constant throughout the whole sequence (this can be well seen on the corresponding diagrams in the frame-accurate comparison section). It's also worth mentioning that this codec does not use drop frames.



Picture 32. battle, frame 1079, 100 kbps

Picture 33. battle, frame 1079, 2340 kbps

Morgan Multimedia JPEG v2



Picture 34. PSNR/FrameSize diagram for MM JPEG v2

Codec's features:

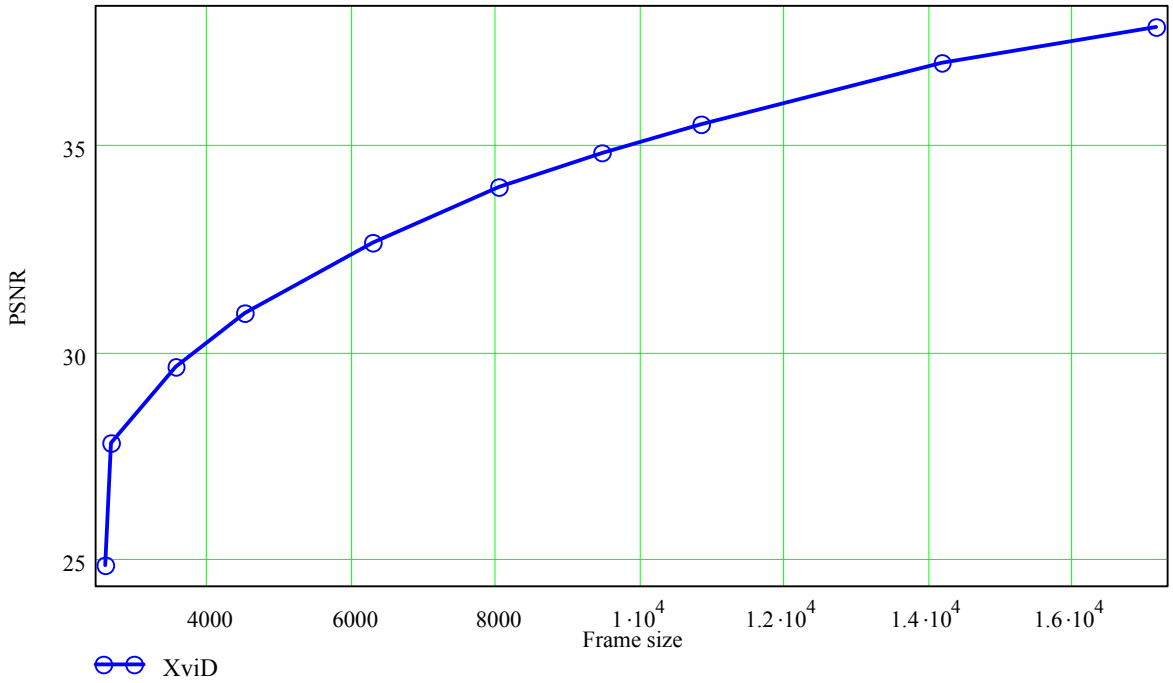
- There were 15 errors during its free-running testing, which stopped the compression process. Also codec created several clips with errors (lost index error).
- The codec does not keep low bitrate; it used the same bitrate value for all the bitrate values from 100 to 938 kbps. That's why several point on the diagram turned into one (the first point).

It should be mentioned that the codec significantly increases low bitrate; the quality that comes as a result of it can be viewed on the pictures below.

Picture 35. battle, frame 1079, 100 kbps

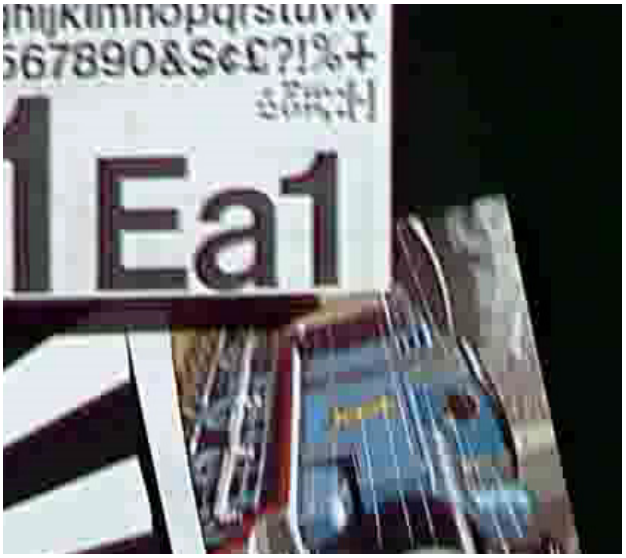
Picture 36. battle, frame 1079, 2340 kbps

Xvid Mpeg4 Video Codec 2.1



Picture 37. PSNR/FrameSize diagram for Xvid

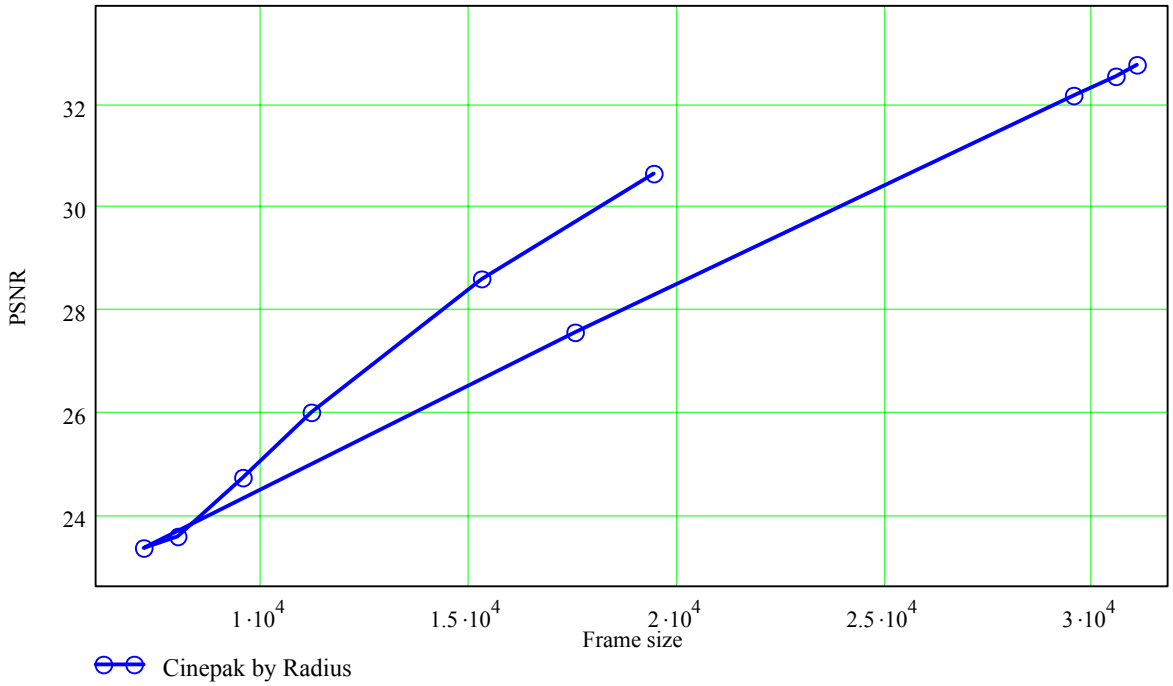
This codec works rather well. It had no problems during its free-running testing and as a result all the video sequences were compressed without any errors.



Picture 38. bbc3di, frame 64, 100 kbps

Picture 39. tensdi, frame 128, 100 kbps

Cinepak by radius



Picture 40. PSNR/FrameSize diagram for Cinepak

Codec's features:

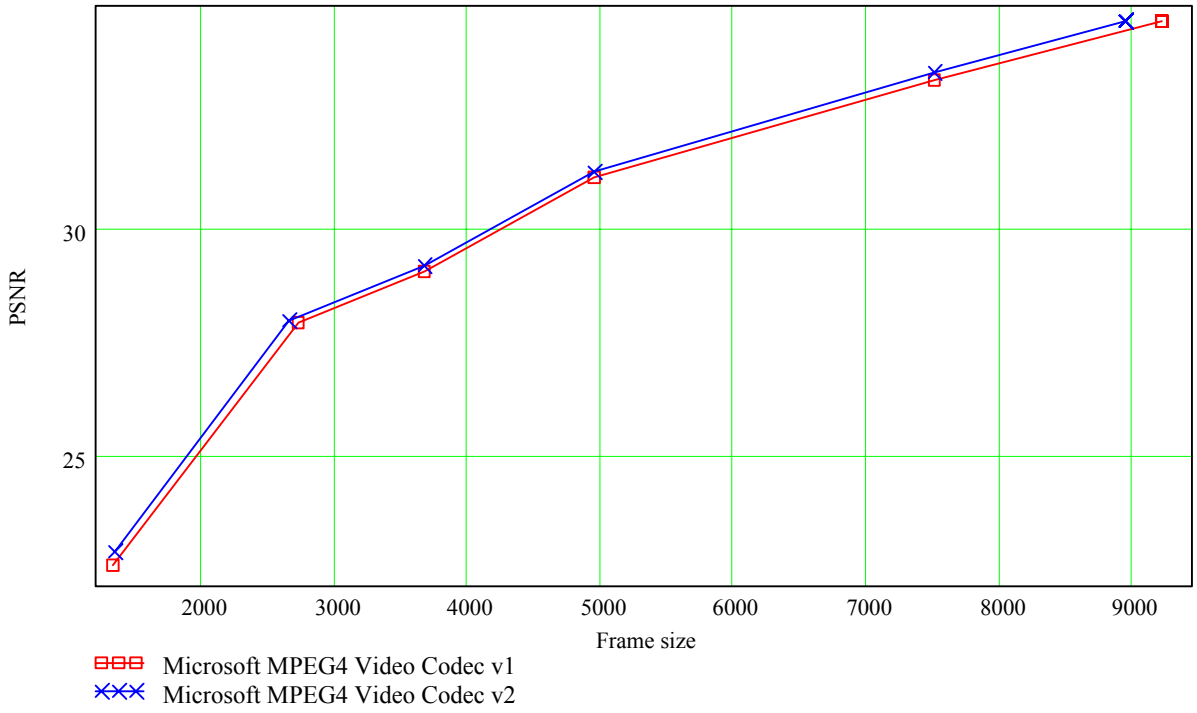
- This codec can be characterized by the largest size of the output files. The size of the folder with compressed sequences is 1.3 Gb while the size the same folder for the other codecs is on average 130 Mb.
- PSNR metric goes not go higher than 33 dB even at the high bitrate, while many codecs reach the same quality at a lower bitrate.
- Branchy diagram structure displays the instability of the codec's work. The shape of the diagram above shows the unsteady dependence of the PSNR value and the frame size on the bitrate settings.

Compressed bus sequence demonstrates great changes of brightness (illumination). On a whole the quality of the compressed sequences is rather good.

Picture 41. bus, frame 28, 700 kbps

Cinepak by radius

Microsoft Mpeg4 Video v1,v2

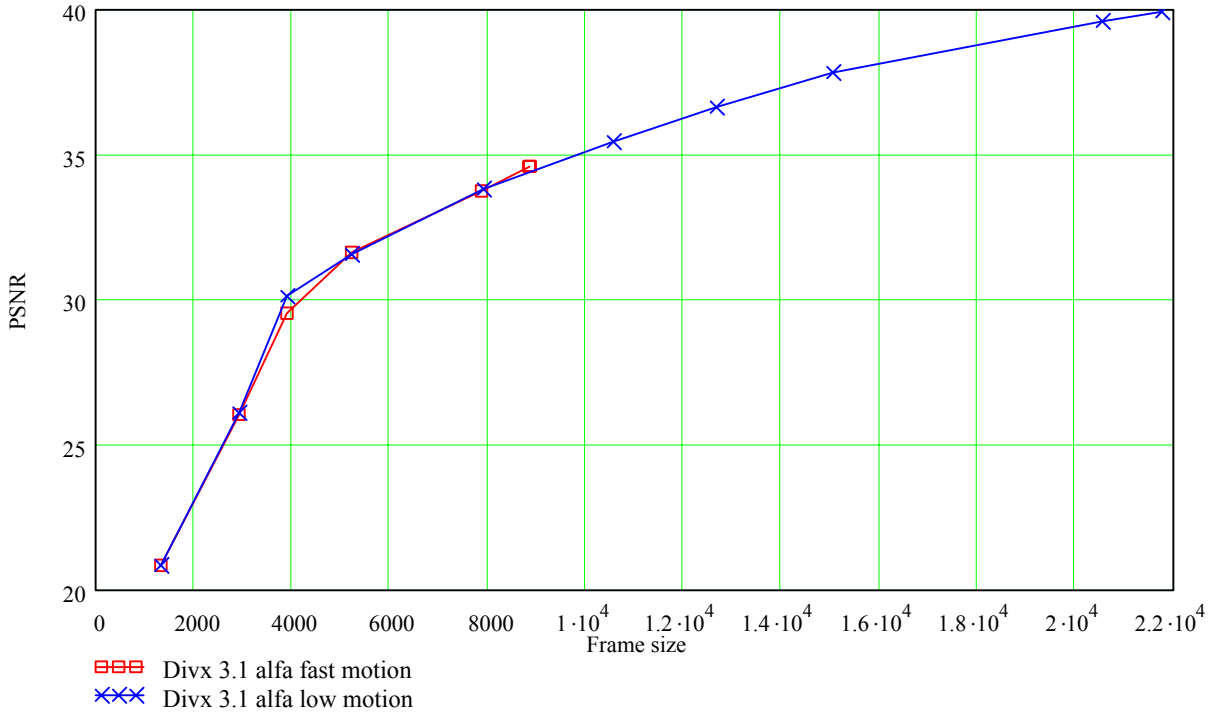


Picture 42. PSNR/FrameSize diagram for MS MPEG4 Video v1, v2

These are the original versions of the Microsoft codec. Both versions work stable, there were no errors during their free-running testing. The diagram consists of less than 10 points, because the codec compressed last several sequences using the same bitrate, which is unlikely for codecs, since they usually ignore low bitrate, not high.

Picture 43. battle, frame 1079, 460 kbps

Divx 3.1 fast motion & low motion



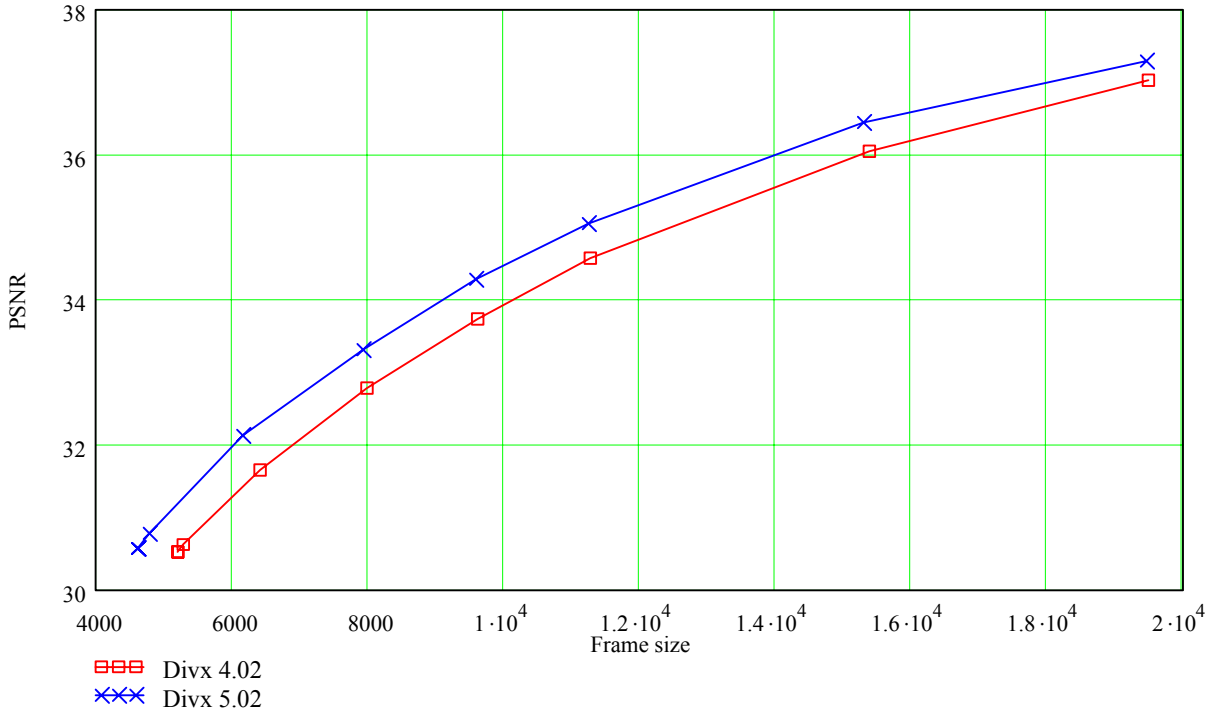
Picture 44. PSNR/FrameSize diagram for Divx 3.1

Six points instead of ten on the diagram related to the fast motion mode are caused by the fact that the codec generated similar files with similar metric for several different values of bitrate. Differences between these two compression modes of the codec can be well seen on other diagrams (see the following sections), although they work almost similarly as a whole. No errors occurred during its free-running testing.

In order to keep low bitrate the codec generates drop frames (see “Drop frames strategy”). On the picture below there is a frame from the sequence compressed with bitrate of 100 kbps. As one can see after comparing this picture with pictures for other codecs, it is a drop frame. Block effect can be also seen on this picture.

Picture 45. battle, frame 1079, 100 kbps, fast motion mode

DivX 4.02 & DivX 5.02



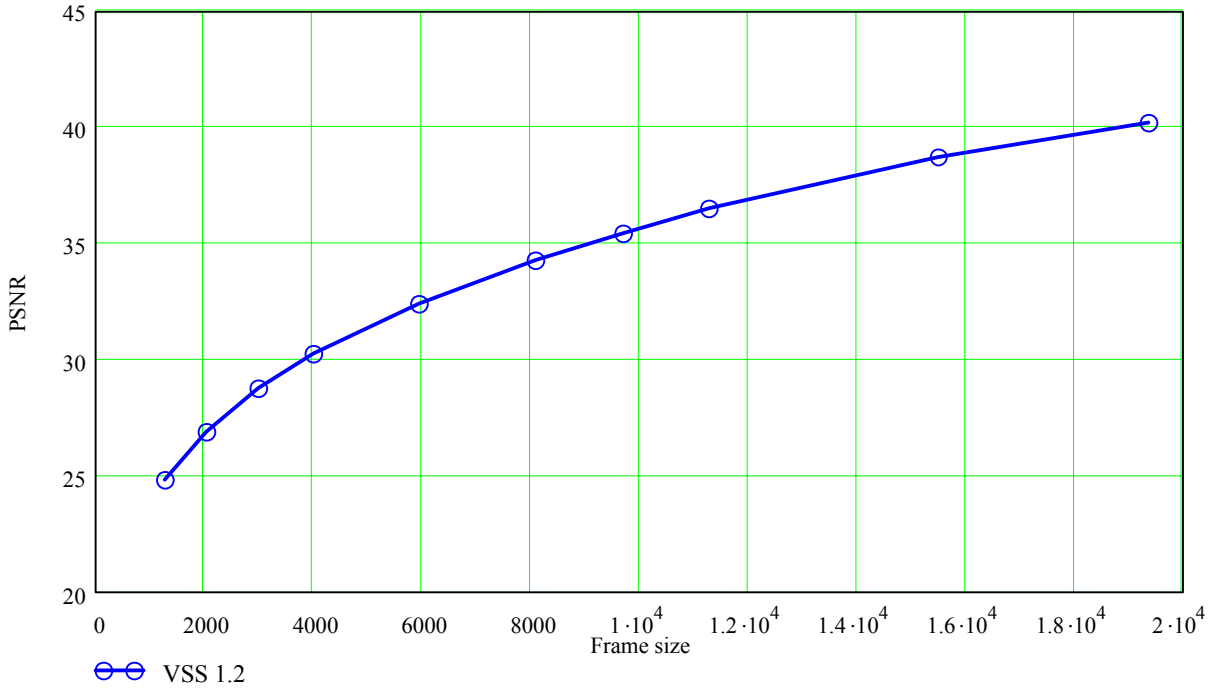
Picture 46. PSNR/FrameSize diagram for DivX 4.02 & 5.02

The diagram clearly represents the results that were achieved in the latest version of the popular video codec. Both versions do not generate drop frames with default settings and do not keep low bitrate. They also support VirtualDub jobs, what lets test them in a free-running way.

Block effect can be easily seen on the picture below.

Picture 47. battle, frame 1079, 100 kbps (Divx 4.02)

VSS 1.2

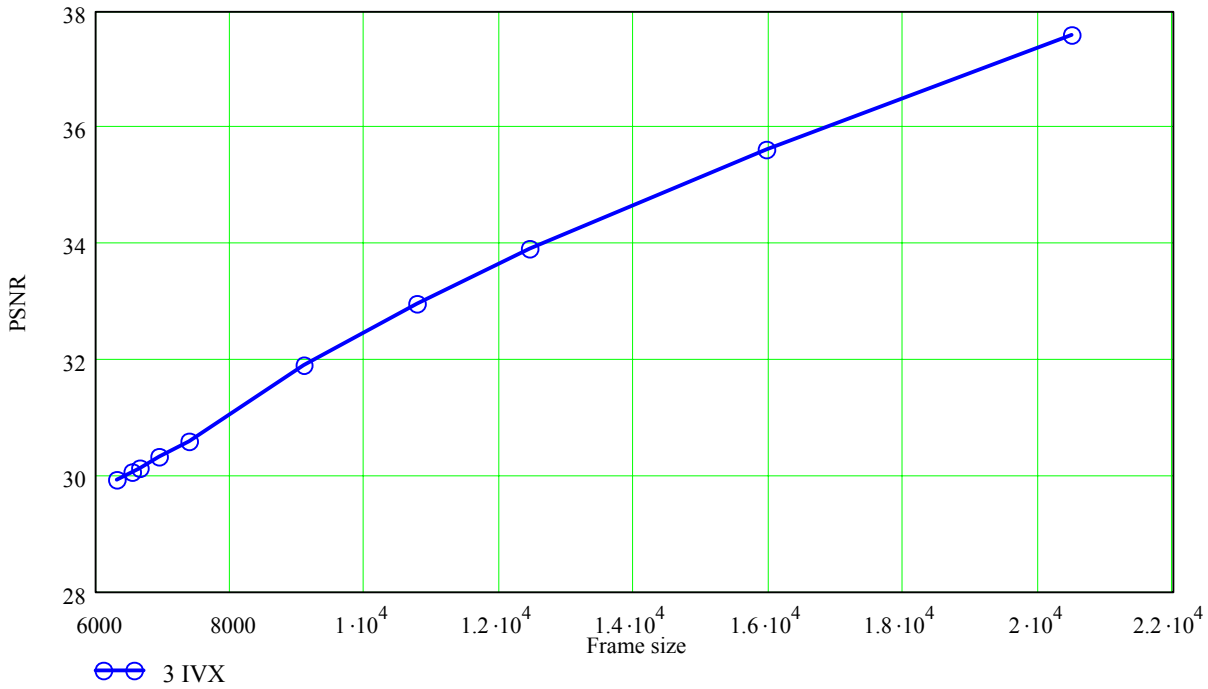


Picture 48. PSNR/FrameSize diagram for VSS 1.2

There is a later version of this codec (1.3), but it requires registration. Unregistered version is unable to perform playback of the compressed sequences, although there are no warnings about it during the compression. Both versions do not support VirtualDub jobs.

Picture 49. battle, frame 1079, 100 kbps

3IVX D4

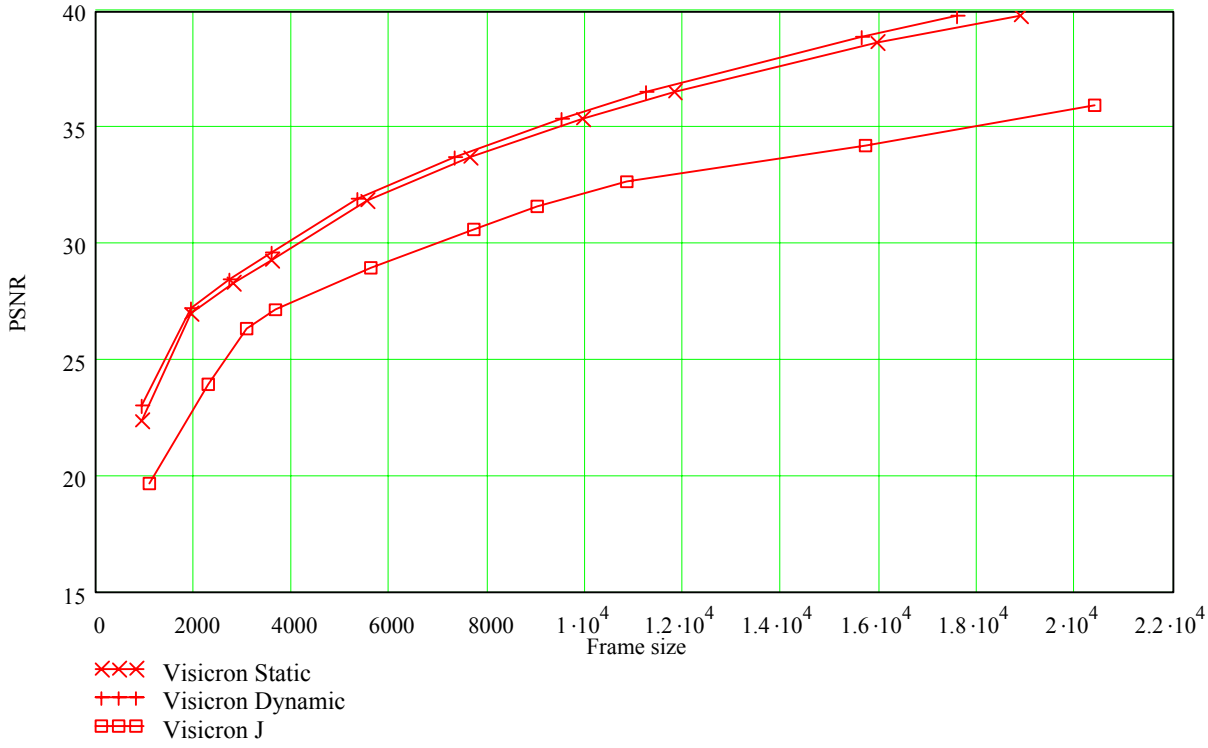


Picture 50. PSNR/FrameSize diagram for 3IVX

There were no errors during the codec's work, but it should be mentioned that this codec doesn't support VirtualDub jobs. It doesn't compress with low bitrate with default settings. It means that it compresses with comparatively high bitrate even if the low one is set. So the quality of the compressed sequence is good enough even when the bitrate value is set to 100 kbps. Block effect can be seen rather well on the frames with fast motion.

Picture 51. battle, frame 1079, 100 kbps

Visicron



Picture 52. PSNR/FrameSize diagram for Visicron

The codec has three modes:

- *Static mode* is stable to the frames lost.
- *Dynamic mode* is unstable.
- *J mode* is oriented on holding web-conferences.

Codec does not support VirtualDub jobs. In the dynamic mode there occurred an error during compression bbc3di sequence with 938 kbps bitrate value; the codec compressed only one frame of that sequence although there were no any error messages about it.

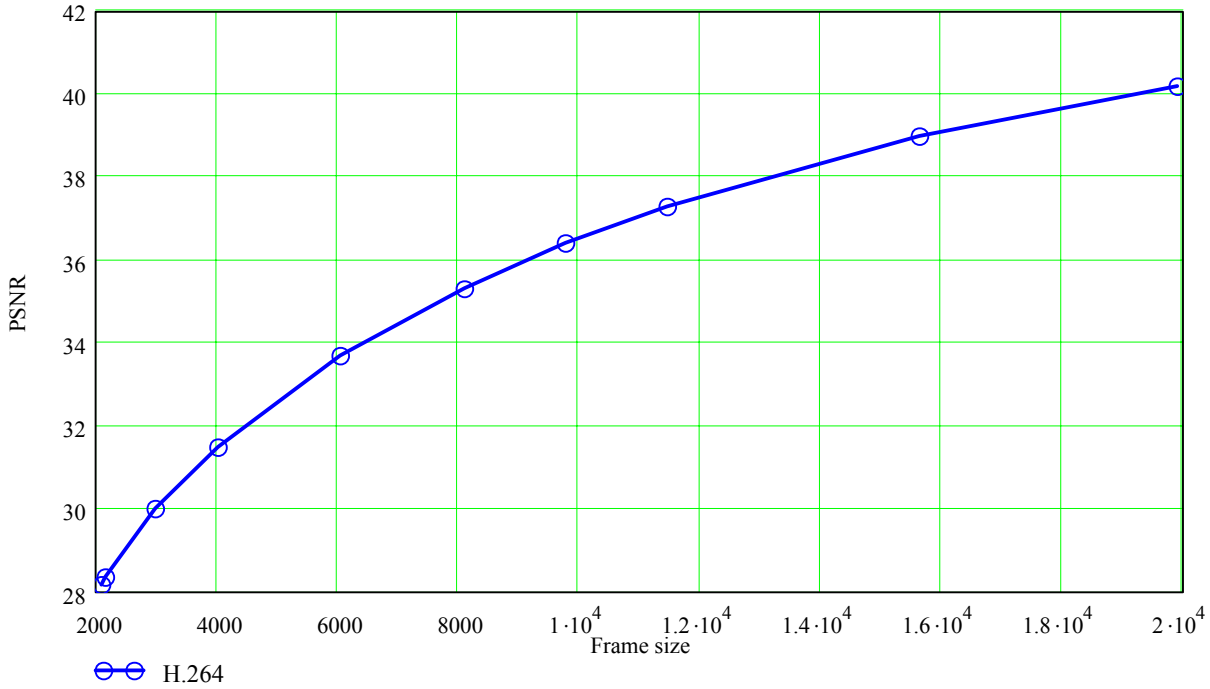
On the pictures below there are frames from the sequence that were compressed in two different modes of the codec with bitrate of 460 kbps. It should be mentioned that since this codec is oriented on web-conferences, it keeps face features rather well. This fact is proved by its name – «Video conference edition».

Picture 53. tensdi, frame 128

Picture 54. tensdi, frame 128

(Dynamic mode) frame from Visicron **(J mode) frame from Visicron**

VSS H.264



Picture 55. PSNR/FrameSize diagram for VSS H.264

Codec does not support VirtualDub jobs. Compression process takes two or three times as long as compression by the other codecs.

Outline

Video Codecs Comparison consists of the following sections:

- **Part 1: Methodology – *this document***
- Part 2: PSNR Diagrams For All Video Codecs
- Part 3: Frame-accurate Comparison
- Part 4: Visual Comparison

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